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BANK REVETMENT ON THE LOWER MISSISSIPPI.

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WITH DISCUSSION.

The following paper is written for the purpose of giving in logical sequence the operations of engineers on the lower Mississippi River in dealing with the problem of bank protection, as derived from personal knowledge and experience and information on the subject gleaned from the scattered appendices in the reports of the Chief of Engineers of the United States Army. Much valuable engineering knowledge is buried in these executive documents that can be resurrected with great difficulty, as the different members of one subject have often been interred in many volumes, frequently covering a considerable range of years.

By the lower Mississippi is meant that portion of the river from Cairo to the mouth, which is, strictly speaking, an alluvial stream, its waters charged with sediment received from its tributaries and taken from its crumbling banks, the amount varying with its course from bend to bar. It flows through an alluvial plain, in great part formed by its own agency.

It is the purpose of the author to give a brief description of the different kinds of revetments used to protect the banks of the river from erosion, their cost, manner of construction, and the results obtained by their use. The relative value of different methods of river improvement, the success and cost of certain projects or lines of procedure as a whole, will not be discussed. The author will confine himself strictly to the details of construction and their evolution from the cruder methods of twenty years ago to the more advanced practice of the present day.

It is a well-known fact that revetment made of brush, cane, straw, etc., has been used in Europe and Asia for the protection of river banks and levees for many years, and it is therefore not a novelty; but the manner in which it is constructed differs very considerably, even in this country, varying from the log mattress of the sea wall to the closely woven fascine revetment of the non-tidal stream.

It is customary in protecting the banks of a river to use, if possible, the material found in most abundance and procured most economically in the immediate vicinity of the improvement. On the lower Mississippi the foreshores, bars and low-lying lands are covered to a great extent with an abundant growth (thousands of acres) of willow and cottonwood saplings that can be woven into mattresses with great facility, when cut and shipped to the working ground. Stone, though not so plentiful, is obtained at reasonable prices from the quarries of the bluff formation of the Mississippi, the foot-hills of the Ozarks on White River and other portions of Arkansas, and also from Alabama, but a few hours distant by rail from the lower river; and as ballast from vessels in the port of New Orleans. The other articles of which the revetment is manufactured—spikes, wire, cable, manilla rope, staples, etc.—are purchased generally in a northern market. The labor employed is procured from the floating white population of the country and the colored residents of the southern States bordering on the Mississippi.

The purpose of the revetment, as before stated, is to prevent the bank caving (which, without protection, is constantly occurring on the concave side of the river), and thus reduce the load of sediment carried to the bar, preventing its rapid growth; to maintain a normal width and depth in the bends, and to protect valuable property in danger of being destroyed by the constant action of the currents.

The difficulty of constructing and maintaining works of this character on the Mississippi River is very great, owing to the excessive variation in the height of water surface and the volume of discharge, the great depths, swift and changing currents in the caving bends, and the short season when the water is at a stage sufficiently low to admit of building and sinking mattresses.

The methods at first adopted on the lower Mississippi to keep the banks from caving were similar to those in use on the Missouri, which, though a smaller stream, is subject to much the same conditions of flow and bed. The first revetment used on the lower river was purely local and for the protection of property, and not with a view to bettering navigation or in any way improving the river for the purposes of transportation. Prior to 1878, as the river at Memphis had been encroaching on the shore in the vicinity of Wolf River and below, threatening the destruction of valuable business houses and other property, an appropriation was granted by Congress to be expended under the direction of a United States engineer officer, for the amelioration of these very serious conditions.

At Vicksburg, in the spring of 1876, a cut-off occurred, leaving the city on the bank of a lake, the west side of the new channel having rapidly caved away, thus carrying the navigable water farther and farther from the town wharves and landing. To check this action, on the recommendation of a board of United States engineer officers, Congress allotted funds for the promotion of a project of improvement having as an essential factor the prevention of the bank caving at Delta Point.

At New Orleans a project was formulated by the United States engineer officer in charge of that district for the protection of the wharves threatened by the scouring action of the water, the purpose being to build a timber bulkhead in about a line with the outer edge of the wharves, and also to carpet the slope below that line with mattresses. In 1878 money was obtained from Congress and the next year work was commenced. The methods employed by Captain Eads on the jetties at the mouth of the river will not be considered, as that work consisted in the building of new (artificial) banks rather than the protection of the natural ones, and also as the conditions directly at the gulf are so dissimilar to those existing above. The lower reach at the jetties partakes somewhat of the character of a tidal estuary, as

well as a sedimentary river, though no tidal inflow is perceptible at the surface.

The lower Mississippi River flows through a low-lying land subject to inundation, composed for the most part of sedimentary deposit formed by the river itself, though undoubtedly having its origin at some points at a period remotely antecedent to the fluvial existence. The material as exposed in the caving banks is found generally in horizontal strata of varying thickness and consistency, no definite order being maintained, the position of each layer having been determined by the special locality, and its location relative to the current of the river during its formation. A section of the bank at Delta Point above low water shows a thick top layer of soil; then buckshot; then sand; then a thin layer of clay and buckshot; then sand; then yellow clay; then sand, underlaid by a thick layer of blue clay reaching to low-water level. At some points the section is mainly sand; at others, the major portion is buckshot, the latter being a tenacious black clay, which, if continuous and not intersected by layers of sand or lighter material, would withstand the action of the water almost as successfully as rock. This indicates how impossible it would be to modify the form of revetment to suit each arrangement of strata, changes in which may occur in less than 100 ft. length of bank.

The object has been to endeavor to construct all revetment sufficiently strong to protect the weakest material. The position of the strata and the drainage of the back-lying lands are also potent factors in the problem of improvement by revetment, as the lighter strata, sand, etc., act as drains for the ground-water at low stages, causing much damage by sloughing.

The position and extent of the soft strata in the bank, the drainage of the adjacent land, the degree of curvature of the bend, the slope and velocity of the water, the position and depth of the channel, the kind of growth on the land, and the stage of the river, determine the extent, rapidity and kind of caving. Most of the bank caving occurs at medium high stages of river, and is specially extensive on a rapid decline after a continued high water. The channel of the river in the bends probably deepens or scours at most points during the high water and rising river, when the velocity is greatest; but the actual caving of the bank does not as a rule take place until the support of the water has been taken away.

At some points the bank caves at all stages, this action being caused principally by abrasion; while at others, the combined action of the seep or drainage water through the soil and the undermining of the foot of the slope causes what is termed sloughing. This kind of caving is most difficult to contend with, the bank often sliding out in great sections, carrying with it willows and stone and necessitating a re-adjustment of the work for some distance above and below. At the bank-full stage in many places the thread of maximum velocity occupies a position approaching more nearly the center of the stream, thus decreasing the scouring action at the sides.*

Vicksburg Harbor, 1878 to 1881.—The first work at Delta Point, opposite Vicksburg, consisted of the revetment of the bank below medium low water, it being expected that the upper bank would be graded to a gentle slope by the action of the water, not needing other protection.

The plant, labor and materials, with the exception of rock, used in the early construction was furnished by the Government, the rock

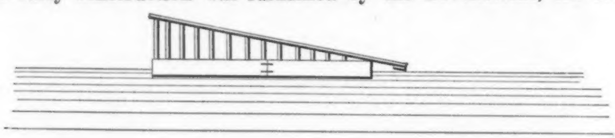


FIG. 1.

being contracted for. The protection work consisted of willow mattresses 50 ft. wide by 150 ft. long, constructed on floating ways. An attempt was made in November, 1878, to use stationary land ways, but they caved into the river, and the method was abandoned. The floating ways or barge on which the mattress was manufactured consisted of two coal boats, each 165 ft. long, with the gunwales cut down, placed parallel to each other and bolted together (see Fig. 1). On them the ways proper were erected, having inclined skids 6 ft. apart running across the barge, supported at intervals of 4 ft. by posts. The upper end of the skids or runs was 8 ft. above the gunwales, the lower end resting on the barge. This inclination proved too slight for starting the

* A recorded instance of bank caving occurred in Gouldsboro' Bend, New Orleans Harbor, December 14th, 1887. Just above a spur dike, a mass of earth in the shape of a semi-ellipse in plan, having an axis of 300 ft. and semi-axis of 60 ft., moved downward and outward into the river. The movement was regular and at the rate of about ½ in. per minute. The bank was quite steep before the caving. The cause was a pond on the bank from which the water seeped into the river.

mattress, and had to be increased. The runs extended 6 ft. beyond the edge of the barge, resting in the water when the weight of the mattress was on them. The timbers of the framework were 4 x 6-in. cypress, the runs being of long leaf pine. Stringers were fastened below the runs at the lower end, to strengthen them. On this barge a mattress 50 x 175 ft. could be constructed.

Willow brush and poles were obtained from a bar in near proximity to the work and placed on barges. When ready to manufacture the mat, these barges were towed alongside of the mattress ways, and the material taken from them as needed, the mat barge being fastened to the shore, and the mattress barges to the material barges by manilla rope. The laborers on the material barges passed the brush and poles to the mat-builders on the mat barge, as required. The mattress construction consisted in first placing longitudinal stringers made of willow or cottonwood poles 6 ins. in diameter at the large end, fastened

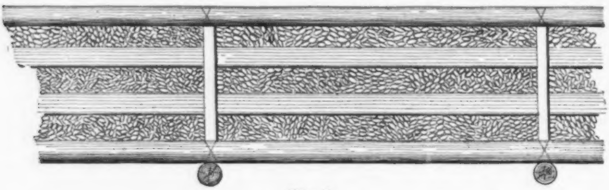


FIG. 2.

together with wire and spikes, 8 ft. apart on the runs, each stringer stretching along the barge the full length of the mattress. In a mat of 50 ft. width there were about seven stringers. Across these and on top of them were then placed a set of transverse stringers of the same dimensions, also 8 ft. apart, fastened to the longitudinal system at the intersections with wire and spikes. At the intersections were also inserted, in a vertical position, pins of swamp hickory 1 in. in diameter and 3 ft. long.

On top of this framework and between the pins were then laid five layers of small willow brush, each layer at right angles to the one above and below, until a thickness of 2 ft. was obtained (see Fig. 2). On this brush was placed a set of transverse stringers 8 ft. apart, in the same manner and of the same dimensions as those below. The upright pins were let into these stringers and secured by wedges and nails, thus connecting the upper and lower system of poles. No. 12 wire was

also used at the intersections to connect the top and bottom frames, adding strength to the bond.

When the mattress was completed, ropes were fastened to it in such a manner as to be readily freed by toggles when on the bottom. Then it was launched from the ways into the water and towed to the part of the bank to be revetted. A large coal boat bottom was used as a mooring barge, to which the mattress was fastened by lines, the mooring barge being held in position by shore lines (as shown in Fig. 3); the mat had independent lines to the shore, that could be released by trip toggles after sinking. When in position and ready for sinking, sufficient rock was thrown from the mooring barge and small stone flats, 30 ft. long by 12 ft. wide, to cause it to settle to the bottom. A steamboat was constantly employed in placing the barges, towing, etc.

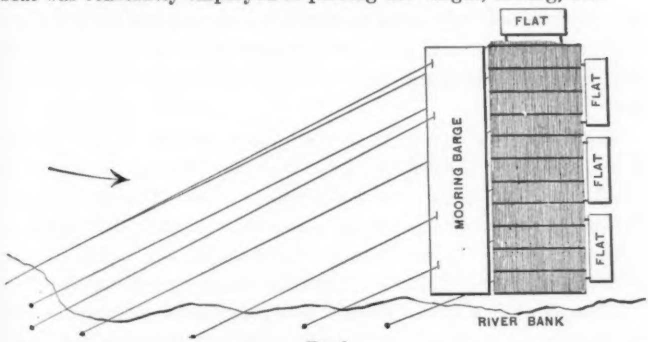


FIG. 3.

These first mattresses extended from about the low-water line 150 ft. down the subaqueous slope. One could be made and sunk in a day with the untrained labor and crude appliances, and under the unfavorable conditions of weather and river stages. In 1879 a great number of these mattresses were sunk successfully at Delta Point. The mat-builders became so proficient that as many as four mats were sometimes made and sunk in one day. A considerable reach of river front was thus revetted. In some instances, the depth of the water at the outer edge of the mat was 80 ft.

Experiments were then made with floating screens, similar to those used by Colonel Suter, U. S. A., on the Missouri, but they proved very unsatisfactory.

The local engineer gives the cost of revetment with these early

mats as about $18 per lineal foot of bank ($12 per square)* under favorable conditions. It must be remembered that this only represents subaqueous work, the upper bank not being improved in any manner. In 1880 it became apparent that the protection of the subaqueous bank only, leaving the upper slope exposed to the destructive action of the currents, was bad practice, and that some method would have to be adopted for its preservation. This was accomplished by grading the upper bank to a slope of about 45° with shovels, from about the low-water line to the top, and placing on this uniform slope a revetment composed of willow fascines laid to a thickness of about 8 ins., having on top transverse poles which were fastened to the ground by wires to deadmen, thus holding the willows in place. A deadman is a beam set horizontally in the ground forming an eye or loop as shown in Fig. 4. No rock was used on this revetment.

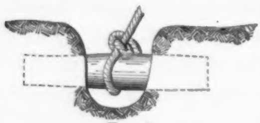


FIG. 4.

In 1881 it was proposed to institute a new method of bank grading which had been successfully applied on the Missouri, viz., the removal of the material of the upper bank by means of a jet of water. For that purpose a fire pump was placed on a barge 16 ft. wide by 98 ft. long by 3½ ft. deep, the pump being of the Dayton cam make, with cylinders 16½ x 18 ins., and water plungers 9 ins. in diameter, and with two 4-in. discharge pipes. On the barge was also a boiler 42 ins. in diameter by 20 ft. long, with two 14-in. flues. The total cost of the grader complete was $3 679. This machine was not used during the season of 1881, owing to adverse conditions of river stage, etc., the work, as before, being confined to mat-building; the method of mat construction was entirely changed, the pole frames at the top and bottom and the hickory pins, which were found to be weak, being entirely dispensed with, and in their place a wire netting substituted, fastened by wire stitches made through the mat.

Before giving the details of construction, it will be well to describe the mattress boat on which this form of revetment was built. It consisted of two barges 20 ft. wide, 150 ft. long and 3 ft. deep (see Fig. 5), with cypress gunwales 8 ins. thick at the bottom and 6 ins. at the top, with yellow pine bottoms 2½ ins. thick; with a rake at one end

* By a square is meant 100 sq. ft.

allowing an overlap on the shore for connecting the mat to the revetment above water. The barges were rigidly fastened to each other by beams 8 x 18 ins. in section and 30 ft. long, a 9-ft. space being left between. This space was spanned by 4 x 6-in. sills, at intervals of 5½ ft., which supported the posts, 4 x 6 ins. and 6½ ft. apart, on which the runs rested. The runs or skids were 4 x 6-in. cypress, beveled on the upper side, and were 5½ ft. between centers. The top of the runs on the high side was about 13 ft. above the water, and on the low side they rested in the water about 8 ft. outside of the gunwales. There was a break in the run slope at 37 ft. from the top, the upper grade being about 6½ to 1, and the lower 3½ to 1. The lower ends of the runs rested upon a 4 x 10-in. guard sill, running parallel to the barge, to which they were bolted. A floor 4 ft. below the top of the runs enabled men to work under the mat; it also acted as a brace to the posts. A platform 8 ft. wide projecting from the high side of the ways extended the whole length of the barges. On this platform was a drum on which

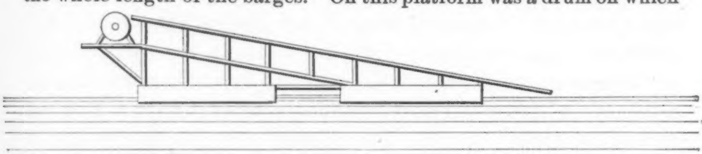


FIG. 5.

was formed the wire netting. It consisted of a wooden frame 12 ft. in circumference, with a 6 x 6-in. wooden shaft. On this circumference were fitted wrought-iron bands 1½ ins. wide and ¼ in. thick. These bands were in pairs, 6 ins. apart, each pair 2 ft. between centers. Around the circumference of the bands were nibs of round iron ½ in. in diameter, 1½ ins. high, and riveted to the band. The nibs were in pairs also, 1 in. apart, and 12 ins. between centers of pairs. The nibs were exactly opposite each other on the different bands, making continuous lines along the drum.

In making the netting a No. 8 wire was placed along the drum between the nibs, then two transverse wires were placed between the bands, one over and the other under the longitudinal wire. Before the drum revolved, bringing a new set of nibs to the top, a 2-ft. mesh was formed by twisting the cross wires firmly around the longitudinal wire with a steel pin.

In constructing the mattress, longitudinal poles were first laid 8 ft.

apart, not for the purpose of strengthening the mat, but because it was found impossible to launch it without them. On these poles was placed the wire netting of the same dimensions as the proposed mat. On the netting was placed the brush in three layers to the thickness of 1 ft. Then the willows were sewed to the wire netting with No. 12 wire, the seams being made 4 ft. apart, and in lines parallel with the length of the mat. In taking the stitches one man stood on the top of the mat, and another on the platform under it. The lower man carried a coil of wire, playing it out in the line of the proposed seam. The man above carried a ⅜-in. iron needle, 3 ft. long, having an open slot in one end and a bend in the other. He thrust his needle through the mat at intervals of 2 ft., catching up the wire from beneath in the slot and pulling it to the upper surface, where a wooden toggle was placed in the bight of the loop and fastened to it by a staple, holding it temporarily in place until the entire seam was made, when a top wire was run through each loop, and a turn taken around each loop, thus forming the completed seam. It was proposed at first to build continuous mattresses of this form, but for some cause the purpose was abandoned, and mattresses 50 x 150 x 1 ft. were constructed instead. Cross rows of poles were wired to the top of these mats, to keep the rock ballast from rolling off. The operation of sinking was similar to that employed for the pin and pole mats of 1878.

Permeable floating screen revetments were experimented with again, but the results were not satisfactory, the high water carrying them away. They proved serviceable on the Missouri River, but on the lower Mississippi they were entirely too light in construction to be of permanent value.

Memphis Harbor.—The work for the protection of the river bank at Memphis was in progress at the same time as that at Delta Point, Vicksburg. In 1878, owing to the prevalence of yellow fever, but little was accomplished, but the next year a full and successful test was made of the revetment method of improvement for that locality. Neither the appliances for manufacturing the mat nor its construction were similar to those adopted at Delta Point. Stationary mattress ways were formed by cutting the bank to an angle of 40° and placing the slope posts 5 ft. apart, on which rested 4 x 6-in. stringers rounded on top, and drift-bolted into the posts. In the mat construction various designs were tried. At first four frames of willow poles

were used, the first frame at the bottom being formed by placing poles 4 ft. apart, and other poles transverse to them at the same interval. These poles were fastened together by ¾-in. oak pins. On this framework was placed a layer of willows; then another framework in 12-ft. squares; then a second layer of willows, and another framework in 12-ft. squares; then a third layer of willows, on top of which was placed the last frame of poles 4 ft. apart, as in the bottom frame. Each intersection was firmly pinned through the mat, and fastened also by No. 12 annealed wire, thus forming a very thick mattress. This structure was found to be unnecessarily heavy and thick and was therefore changed, the two 12-ft. pole frames being dispensed with, and only two frames used, one at the bottom and one at the top, with poles 4 ft. apart pinned every 8 ft. by 1-in. oak pins, and well wired. These mats were sunk in water 80 ft. in depth at some points. The sinking was accomplished in a manner similar to that followed at Delta Point. The stone at this locality cost $2 45 per cubic yard on barges at the work. Up to June, 1880, 1 300 lin. ft. of bank had been protected at this point, and in addition to the subaqueous work, upper-bank revetment was constructed of the same design as the mattress, making a total of 2 385 squares of revetment. The distribution of material in this work is shown in Appendix A. Up to 1882, 3 125 lin. ft. of bank had been protected, and the caving was reported at least temporarily stopped.

In 1881 the pin and pole method of mat construction was abandoned here, and a wire frame substituted. No. 10 annealed wires were laid longitudinally and 6 ft. apart on the same ways used for the old mats, the end of each wire being turned about a binding pole and held temporarily by a strong stake. At right angles to these wires and 6 ft. apart others were also fastened at the ends to binding poles and temporary stakes. At the intersections these wires were fastened by other wires of sufficient length to reach well up on stakes to which they were temporarily attached. These stakes were driven into the ground and reached an elevation 2 ft. above the mat, preventing it from sliding off the ways during construction. On the bottom wire frame thus formed, willow brush in four layers was laid to a thickness of 18 ins., and over it a wire frame similar to that below was placed, and fastened to it through the mat by the short wires that were temporarily held up by the stakes. At the ends the wire frames were fastened to a sys-

tem of poles which formed, when joined together, a strong selvage around the mat. These new mats were 125 x 50 ft. and 18 ins. thick. They were launched from the ways and sunk in a manner similar to the others, with the exception that a portion of the ballast was gravel in sacks tied to the mat and loose. This proved more economical at first than stone, but was neither so satisfactory nor so permanent, being too light to resist the force of the current. During the same season, 1881, a part of the upper bank was revetted in the following manner: First, brush was laid on the bare slope in three layers to a thickness of 18 ins.; then wire was placed over it and fastened to specially formed stakes, which were driven into the ground, stretching it tight over the brush, thus binding it down; then the brush was given a good covering of stone. About 900 squares of this mat and 130 squares of upper-bank revetment were constructed, with the expenditure of material shown in Appendix A.

New Orleans Harbor.—The early revetment work at New Orleans was to prevent the wharves from being washed into the river. In 1878 the project consisted of the erection of a bulkhead built of pairs of piles, the piles in a pair being 3 ft. apart, and each pair 6 ft. from the center of the other pair, all connected at the top and low-water line,* and of the sinking of cane mats along the subaqueous slope.

The mattresses were constructed of fishpole cane, being, when completed, 2 ins. thick, 25 ft. long and 24 ft. wide. At first they were made by hand, two galvanized iron wires being used as the warp, woven with the shoemaker's stitch, one wire running over one cane, and under the next, over the third, under the fourth, and so on, the other wire being reversed, thus crossing the first and forming loops, but being fastened only at the end canes. A split was made in each cane through which it was hoped sediment would pass and help to sink the mat. Seven double strands of wire about 4 ft. apart were used for each carpet. Afterward a loom was used, and spun yarn substituted for wire.

When eight of these small mats or carpets were completed, they were taken to the floating ways and placed thereon and connected, making a mattress 200 ft. long by 24 ft. wide. At first they were ballasted with old iron boiler tubes filled with sand and fastened to them. They were ballasted on the floating ways, the ways being after-

* Behind these piles and up to the low-water line were to be piled brush fascines, forming a brush wall.

ward moved up to the line of piling forming the bulkhead, and the mattress fastened to it by iron rings. The ways were then pulled out in the river by a tug, and the mat thus launched was sunk in place on the bottom. Stone was not used, as it was deemed necessary on this steep subaqueous slope to fasten the ballast to the mat to prevent its sliding off. The cost of a square of this cane carpet was $12 87. In 1879, owing to the change from hand weaving to loom work, and the experience gained by the employees during the first season, the cost was reduced to $9 88 per square.

Seventy-four carpets were made, averaging 200 x 26 ft.; 1 116 lin. ft. of bank were revetted, and about 1 496 squares of river bed covered, at a cost, as stated, of $9 88 per square, and $13 38 per lineal foot. The officer in charge reports it was suggested that shrimp, which are known to eat the oakum out of the seams of vessels lying in port, might attack the spun yarn used in construction of the mats, but experiments indicated that there was nothing to be feared from this source.

In 1880 a contract was entered into for the sinking of mattresses at 65 cents per square yard, or about $7 22 per square. Anchorage piles were driven as before, and cane mattresses 200 x 70 ft. sunk with sand bags. The mats were made of 40 sections, 14 x 25 ft. each, sewed together. For mattress construction, a float was used formed of eight coal barges fastened together, supporting launching ways, the dimensions over all being 170 x 206 ft. The skids had a slope of 7½ ft. in 170 ft.

An attempt was made to construct and sink a mattress 140 x 200 ft., but it proved a failure, so the ways were changed for mattresses 84 x 200 ft., and the slope of skids increased to 8 to 1.

For the purpose of mooring the mattress in the desired position preparatory to sinking, three flatboat gunwales were used, so placed as to form a right-angled triangle with the altitude along the piling and the base normal to the shore, the diagonal barge being supposed to fend off drift. To the barge forming the base of this triangular mooring plant, the mattress was fastened, and, after launching, also to the ways. It was thus sunk with guides on three sides, with lines to the gunwales above, to the ways barge below, and to rings on the piling of the bulkhead. After sinking about five of these mattresses, the contractor's plant was destroyed by drift, and the work abandoned. Work was commenced again under a new contract later in the same season, and

27 cane mats 200 x 84 ft. sunk successfully, covering about 2 268 lin. ft. of bank.

In 1881 a board of officers was appointed by the Secretary of War to consider the value of revetment placed up to that time, and the desirability of a change in the project and methods of construction.

After a survey of the locality had been made and the subject of improvement thoroughly studied, the board submitted a report condemning the plan on which the work was based and the methods of construction adopted, as ineffectual in accomplishing the desired end, and recommended that changes be required by the city government in the construction of wharves by companies and individuals, and also that at certain points mattresses be sunk 400 ft. wide, made of brush, not cane poles, costing about $28 per lineal foot. A project based on the report of this board of engineer officers was adopted by the Mississippi River Commission, but no further work was undertaken until the season of 1883.

It may be well to state here, for those not familiar with the Mississippi River and its phenomena, that below Baton Rouge, which is 1000 miles from St. Louis, or 820 miles from Cairo, its general appearance, physical features and properties and mechanical forces are quite different in degree from those existing above. The slope is less, the average depth much greater, the width less. No obstructive bars or crossings occur in this portion of the river. The caving is comparatively slight. The range from low to high water at New Orleans is about one-third that at Arkansas City. The current velocity at low water is very low, and the radii of the bends are greater.

With such a radical difference in the agencies of bank destruction it can readily be seen that a difference in means for protection will follow. The subaqueous work is placed with greater facility and a much lighter form of revetment is practicable and efficacious. Interrupted or broken revetment and dikes with unprotected intervals produce better results than in the upper river, where the range of water level, currents, depths and instability of the banks are so much greater.

Early Work of the Mississippi River Commission.—In 1879 Congress provided for the appointment of a Mississippi River Commission, composed of three United States engineer officers, an officer of the Coast and Geodetic Survey and three civilians, whose duty should be to obtain

such data as were deemed necessary, on which to base a general project for the improvement of the river from Cairo to the mouth, and execute the same with funds appropriated for the purpose. By 1881 this commission had accumulated a vast amount of information, had made an exhaustive study of the problem, and formulated a project for improvement, which was inaugurated in 1882.

The plan adopted contemplated two distinct classes of work.

First.—Permeable dikes, screens, etc., closing chutes and side channels, thus contracting or narrowing the river in the wide and shallow reaches, and making it conform to a normal low-water section.

Second.—Bank protection work, brush mattresses, and stone riprap to hold the shore or river bank intact, preventing caving and the forming of bars below. To quote the report of the commission to the Secretary of War, dated November 25th, 1881:

"The bank revetments are intended, not only to stop the constant, and in some localities very rapid, enlargement produced by erosion and caving of concave bends, but in addition thereto to check the growth of bars and shoals below, by accretions supplied directly therefrom.

"The process of laying this revetment will vary greatly in different localities, but will commonly, or at least in many cases, consist in first freeing the banks of snags, stumps and brush, and then placing a mattress * * * upon that portion of the slope extending from deep water to a few feet above the water level, and weighting it with sufficient riprap stone to hold it in place.

"The revetment to be afterwards completed by grading the bank above the water level to a proper slope with streams of water under high pressure, after the manner commonly followed in hydraulic mining, and laying thereon a supplementary mattress, overlapping the one previously laid, and extending up to the crest of the bank. * * * Whenever it may be deemed safe to omit the mattress on the upper part of the slope, and place the stone covering directly on the bank, that course will be pursued."

Two reaches of river were at first selected for improvement, viz., Plum Point above Memphis, 40 miles long, and Lake Providence below Greenville, 35 miles long. The work of harbor improvement on the lower river, in progress under the United States engineer officers, was also transferred to this commission.

Radical changes had to be made in the general design of protection work, to make it applicable to long reaches of rapidly caving banks. The harbor mattresses, though of temporary value, could not be said

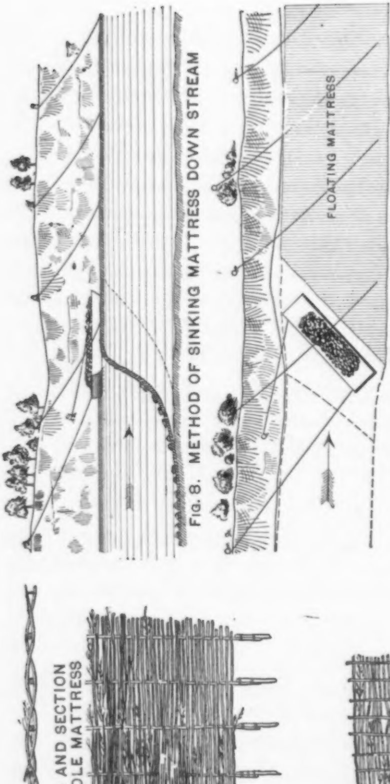


Fig. 8. METHOD OF SINKING MATTRESS DOWN STREAM

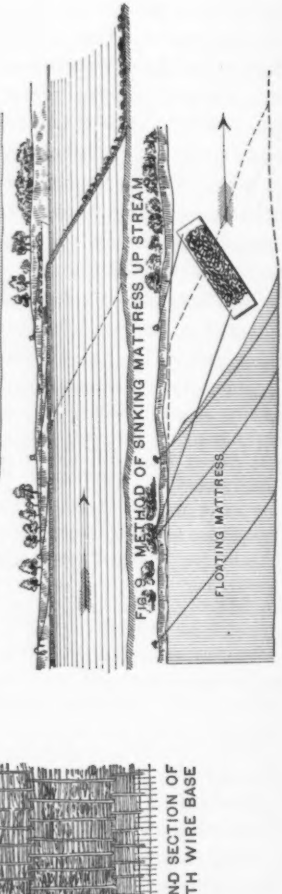


Fig. 9. METHOD OF SINKING MATTRESS UP STREAM

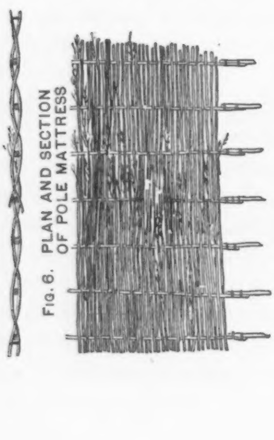


Fig. 6. PLAN AND SECTION OF POLE MATTRESS

Fig. 7. PLAN AND SECTION OF MATTRESS WITH WIRE BASE

to have given permanent protection, because of their small size and detached condition when in place on the subaqueous slope. For long reaches they were very expensive.

The first considerable change was made by increasing their width to three times that formerly attained, and constructing and sinking them in continuous stretches of from 500 to 2 000 ft. Where timber skirted the bank, much clearing and grubbing had to be performed, and in many places great numbers of snags had to be removed by boats built for that special purpose. The thickness of the revetment was very much decreased and the strength much increased by means of iron rods, cables, etc.

The first mattresses used by the Mississippi River Commission on the Plum Point Reach were, when completed, much the same in general form as those constructed at Delta Point in 1881, though the manner of making them was different. They were constructed on a specially designed machine barge and had for their foundation a wire netting of No. 8 and No. 12 wire, the heavier running longitudinally up and down stream, and the lighter transversely, the distance* between the former being 4 ft. and between the latter generally 2½ ft. The brush was carried by machinery operated by steam, from a brush barge, over the mat barge and deposited on the netting, where it was received by men holding hooks, who packed it close together in continuous layers. After a full shift of brush had been deposited upon the netting, brush binders were inserted with their butts into and at least 8 ft. through the netting (see Fig. 7), the tails being bent over the butts last laid and wired firmly through to the netting. The binders were placed at right angles to the brush, and wired at a point directly under the space to be occupied by the succeeding shift. These mats were continuous, ballasted and sunk in the same manner as those to be described hereafter.

A more detailed description of the wire net making machine and general construction of this mat will not be given here, as it was found to be unsatisfactory for many reasons and was soon abandoned.

Work at Delta Point, 1882-83.—In 1882 little or no bank protection was undertaken at Plum Point or Lake Providence Reach or any of the harbors except Vicksburg, where the revetment of Delta Point was vigorously prosecuted with new methods of construction. The

* See the "Report of the Mississippi River Commission," 1883, p. 371.

new mattresses were built after a plan adopted on the upper river in the vicinity of St. Louis and were termed woven mattresses. These new mats were made on the ways built for the wire-net construction heretofore described, the drums and other wire-net machinery having been removed.

The mode of construction was as follows: A low-gunwale flatboat, acting as a mooring barge, 170 ft. long by 26 ft. wide, was placed with the bow to the shore and stern into the stream, being held in that position by 1½-in. manilla lines leading to deadmen on the bank and anchors in the stream above. On the lower down-stream side of this boat, and firmly secured to it by 1-in. lines, were the ways, placed with the lower ends of the runs up stream and the bow of the barge against the bank, the position of these two boats being directly over the

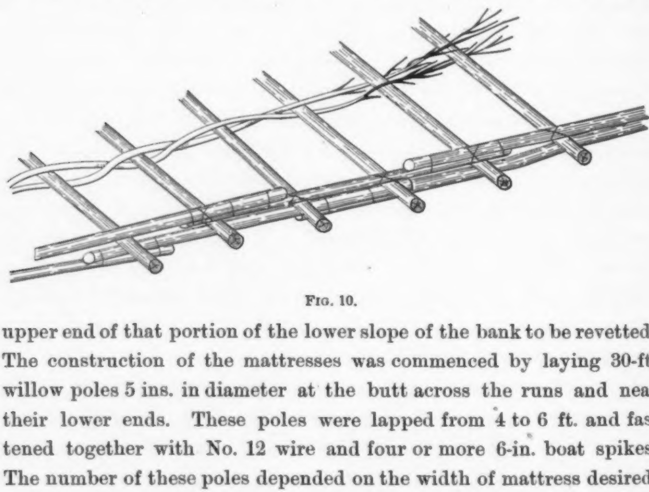


FIG. 10.

upper end of that portion of the lower slope of the bank to be revetted. The construction of the mattresses was commenced by laying 30-ft. willow poles 5 ins. in diameter at the butt across the runs and near their lower ends. These poles were lapped from 4 to 6 ft. and fastened together with No. 12 wire and four or more 6-in. boat spikes. The number of these poles depended on the width of mattress desired.

Longitudinally between the runs, about 6 ft. apart, were placed willow poles of the same dimensions, with their large ends resting on the transverse system and tightly wired and spiked to it as shown in Fig. 10. On the large ends of these longitudinal weaving poles, a third set similar to the first was laid transversely, and all three firmly spiked and wired together, thus forming a mat head or cross-selvage for the woven mat which kept it from unraveling, and acted as a strong fastening in sinking, etc.

Before commencing to weave the mattress this upper frame or head was fastened to the mooring barge by 1-in. lines. Willow brush was then woven over and under the longitudinal poles, the brush being about 30 ft. long and 3 ins. thick at the butt. The weaving was accomplished by placing the brush over one pole and under the next, over the next, and so on, until its end was reached, when it was forced down the runs and poles until the transverse poles or head was reached, to which it was made to fit tightly by means of mauls. This operation was carried on all along the ways by different gangs of men and repeated until the 30 ft. of poles, or one shift, was nearly filled with woven brush, only space enough being left on which to spike and wire other poles, thus making a continuous wooden thread on which to continue the weaving. Every 100 ft. transverse poles similar to those at the head were placed across the mat to give it strength, and longitudinal poles 12 ft. apart were bound to it on top, forming cribs to keep the rock from falling off when sunk on a steep subaqueous slope.

When one shift, or about 30 ft. in length of the mat, was woven, it covered the entire ways, and in order to continue the weaving it became necessary to remove this. To do so the lines holding the ways to the mooring barge were slackened and the ways moved down stream from under the mat, the movement being produced by the force of the current. When the latter was not sufficiently strong, the ways were moved by capstans and lines leading to anchors or the shore below. They were moved just the length of a weaving pole for each shift, until the end of the mattress was reached, when a strong frame selvage similar to the head was constructed, and the last shift launched into the river. The mattress thus floating was held at the upper end by lines to the shore and to the mooring barge, and on the shore side by 1-in. lines leading to deadmen or to trees 30 ft. apart.

These mattresses were about 400 ft. long by 144 ft. wide, the method of sinking being very similar to that employed for the earlier designs.

Rock barges were brought to the outer edge of the mat and fastened to it with lines at intervals of 10 ft. It was then loaded uniformly with rock until under a heavy strain; then, at a signal, these lines were cut, and, as it settled below the surface, the barges were pulled over it and rock thrown on it in quantities sufficient to insure

it remaining on the bottom. The number, size and position of the lines (manilla rope) depended on the force and direction of the current or currents and the depth of water. After each mattress was sunk, sharpened cottonwood piles 40 ft. long and 15 ins. in diameter were driven through the shore side, to keep it from sliding out into deep water where the slope was abrupt. From 60 to 70 ft. of this form of mattress was made per day with 52 men; 30 weaving, 6 at the mauls, 6 binding poles, 4 linesmen, and the rest on the material barges.

The mats were made to lap about 15 ft. when sunk, so that no unprotected seam would be left in the revetment. The piles used were driven about 25 ft. apart and 20 ft. into the ground, being cut off at a stage of about 10 ft. above low-water mark.

After the subaqueous slope had been covered in this manner, the upper bank was graded with shovels as in former years, but this proving very slow and expensive, sluice grading was attempted with fair success.

A trench was first cut with a shovel to the required angle of the slope, 2¼ to 1, and in it was placed a continuous line of wooden boxes, one fitting into the other, forming a trough reaching from top of bank to water surface. A floating pile-driver containing a pump for sinking piles by water-jet was moored near the trough, and supplied its upper end with a stream of water through a hose. The material of the bank was excavated and thrown into the trough with shovels, the stream of water carrying it into the river. After grading as far as the laborers could throw the earth from the shovels, the trough was moved and the slope carried ahead. This method was also abandoned for hydraulic grading on a very much larger scale, the water being forced directly against the bank from a nozzle, to which it was supplied by very powerful pumps built for the special purpose of river-bank grading.

The grader used was designed for the Mississippi River Commission for the special purpose of bank grading. It consisted of a barge 110 ft. long by 30 ft. wide, with 6 ft. depth of hold, well braced and chained to carry the heavy hydraulic machinery. The machinery consisted of a Blake duplex compound condensing pump. The pump had double outside plungers, each 16 ins. in diameter with 24-in. stroke. The high-pressure cylinder was 18 ins. in diameter, and the low-pressure cylinder 36 ins. in diameter, the stroke being the same as

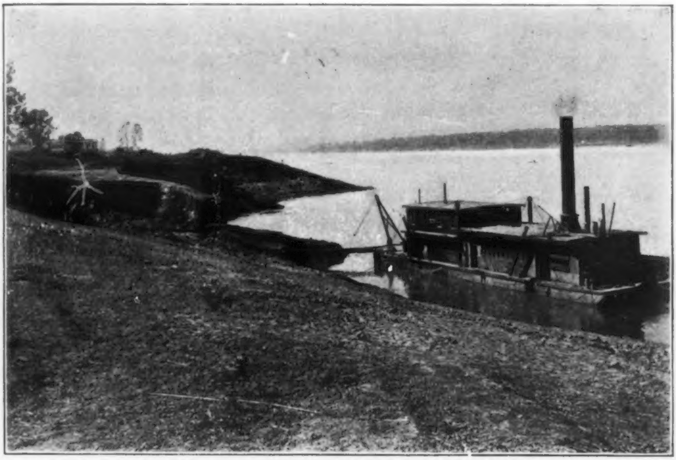


FIG. 1.

FIG. 2.

that of the plungers, 24 ins. The capacity of the pump was 2 000 galls. per minute under a pump pressure of 160 lbs. and a steam pressure of 80 lbs. per square inch.

In connection with the low-pressure cylinder and boiler there was an air pump and condenser, which condensed the steam and heated the injection water. The steam supply was obtained from a battery of three boilers 42 ins. in diameter by 26 ft. long, with five 10-in. flues each. These pumps sucked the water from the river through two 12-in. supply pipes, and forced it through two 12-in. discharge pipes to the forward end of the boat, where they entered a 14-in. boom pipe, which was 65 ft. long and but 10 ins. in diameter at the upper end, and was held in place with accompanying stages by means of shears and steel ropes, the angle made by it with the plane of the deck being governed by a hoisting engine situated in the bow of the boat. The boom pipe had twelve 4-in. openings, with Chapman valves, to which either 4-in. or, by means of reducers, 2½-in. rubber hose was attached. At the end of each hose a 1¾-in. nozzle was used to concentrate the water for the purpose of cutting the bank. The boom pipe and stages were subsequently removed, and the hose connections made directly from the barge (see Plate III, Fig. 1). When all was ready for grading, the bow of this machine was placed against the bank, and the boom pipe and stages lowered. The hose was laid leading from the opening in the pipe to within about 8 ft. of a face which had been cut in the bank as a slope guide, and also as the only practicable way of under-cutting the steep bank and carrying forward the grade. The nozzle, which was attached to the end of the hose, rested on and was turned on a swivel, moving in an oak frame or trestle spiked to the ground. Three nozzles were used, each worked by three men. The slope was cut a little ahead at the upper end, the reason being that by so doing the water, after spending its force on the bank, on seeking a lower level ran close to the lower edge of the face, helping to under-cut it.

The direction of the stream was always kept at a greater or less angle than 90° with the face, as otherwise it would form a pocket in the bank and a water cushion to resist the pressure. It was found that a 2½-in. hose did not work advantageously, owing to the frictional resistance. A 4-in. hose and 1¼-in. nozzle gave the best results. The bank was graded to a slope of 2¼ to 1. Sand and light deposit was

carried off rapidly by the force of the water, but the tougher or more tenacious materials, such as clay and buckshot, of which the Delta Point bank is in great part composed, resisted the jet for some time, but eventually was reduced. With three nozzles an average of 1 300 cu. yds. was removed per day, at a cost of about 4 cents per yard. The inequalities left in the slope were dressed down with shovels or sluice.

After the bank was made comparatively smooth and regular, continuous lines of poles, 30 ft. long by 5 ins. in diameter, well wired and spiked together, were laid on it parallel with the top, the rows being 10 to 12 ft. apart. On these were transverse poles, spiked and wired together in the same manner, in rows reaching from the top to the bottom of the slope, also 10 to 12 ft. apart. These rows were wired together at the intersections. Upon this frame, willows, 20 to 30 ft. long and 2 to 3 ins. at the large end, were laid with the butts up hill, the bushy or leafy part of the top being covered by the butts of those below, each succeeding layer of brush having its butts over the tops of the preceding one, until the water edge was reached. On the brush were placed lines of longitudinal poles directly over those in the bottom frame, and fastened to them by No. 8 wire. This revetment at the water's edge was fastened to or overlapped the mattress work if possible; otherwise a connecting mat was built to make the protection continuous from near the top of the bank to the river-bed. On the upper-bank revetment rock was placed in just sufficient quantity to cover the willows.

The cost of the Delta Point work just described during the season 1882–83 is given in Appendix A. The cost of brush obtained by Government labor was $2 53 per cord; poles, 32 cents each; rock, by contract, $1 90 per yard; wire and spikes, 5 cents, and nails 4 cents per pound.

The total cost of protection, not including grading, was:

Mattress work..........	$2 90 per square.	$4 17 per lineal foot.
Upper bank revetment..	6 89 " "	5 17 " " "
	Total..........	$9 34 " " "

Including towing, grading and other expenses, the cost per lineal foot was about $14.

Work Done in 1883.—In 1883 revetment work was carried on by the Mississippi River Commission on the two principal reaches, Plum Point and Lake Providence, at Hopefield Bend, opposite Memphis, at Memphis, Delta Point and New Orleans. Practically the same methods were employed in 1883 at all points above the mouth of Red River as were used at Delta Point the year previous.

At Bullerton 100-ft. mattresses woven on a wire base were used, the willows being interlaced, as shown in Fig. 7. At Plum Point hydraulic graders were worked similar to that described. The local engineer reported 1 800 to 4 000 cu. yds. of material moved per day at a cost of 2.98 cents per yard.

Electric lights were used for night work. Mattress boats of improved make, over 200 ft. long, but practically the same design as those described, were used. Barges were employed specially adapted to the work. In fact, an entire floating plant had been constructed or purchased specially designed for revetment construction, which greatly reduced the expense and added to the strength and efficiency of the finished protection work. It had been the custom in the work previously performed to press into service anything in the form of a barge that could be used and obtained at small expense, making temporary changes in construction, rather than expend the inadequate appropriations in procuring floating property of special design.

In 1883 wire shore fastenings, instead of manilla ropes, were introduced on a small scale. Fig. 6 shows the woven mats used at Plum Point, and Figs. 8 and 9 the two methods of sinking them when continuous, one with and the other against the current. The revetment was similar to that described. The grading at Bullerton cost from 3 cents to 3.8 cents per yard, the force employed being one nozzleman and two helpers for each nozzle. These men were furnished rubber clothes by the Government.

The cost of the bank protection work on the Plum Point Reach during 1883 was as follows: Mattress work, \$6 30 per square; upper-bank revetment, \$6 40 per square.

At Memphis the small mattresses were still in use, constructed on shore ways and towed to the required sinking locality. They were not made of quite the same thickness. Bank grading was still executed with shovels. The slope and revetment were thoroughly drained above low water by connecting the city drains with special wooden

culverts. The upper-bank protection was slightly different from that used in former years. Wire was laid on the slope forming a 6-ft. mesh. On this was placed 6 ins. of willow brush and on top of the brush wire similar to that below, the top and bottom wire frames being sewed through the brush by separate wire, thus forming one continuous mat. This revetment was secured by placing on it stone, sand in bags and earth. The distribution of material in this work was as shown in Appendix A.

At Hopefield Bend the mattresses were of the woven type, from 250 to 300 ft. long by 140 ft. wide, made in a similar manner to those of 1882 at Delta Point. The upper end before sinking was fastened to the mooring barge by ten 1-in. lines. Two 1½-in. or 2-in. lines were attached to the mattress by means of pin and shackle, and led to deadmen or trees on shore, both passing under the mooring barge. In sinking, the mattress was first ballasted by placing running plank on it and having the laborers carry and distribute rock evenly over it, thus destroying its flotation. When the weight commenced to strain the small lines fastening it to the mooring barge, they were slackened slowly and the mattress allowed to sink until the upper end rested on the bottom. Then a barge loaded with rock was pulled over the mat, being directed by lines from the mooring barge and bank, and the rock was thrown out, sinking the mat. At Delta Point, the fastenings between the mooring barge and mat were cut, the latter sinking rapidly.

The revetment above the low-water line was the same as at Delta Point. Some trouble was experienced from floating drift which accumulated in front of the mooring barge and under the head of the floating mattress, making it difficult to sink the latter. Many expedients were tried to prevent the destruction or loss of work through the pressure of this drift. Diagonal booms and chains were used, but without a great amount of success.

At Lake Providence Reach during the season of 1882 and 1883, the following modifications were made in the bank protection work. In the woven mats alongside of every weaving pole or every alternate one, depending on the strength required, iron rods with welded eyes at each end were placed as the mat was built, the ends of the rods being connected by lap rings or clevises. These rods added longitudinal strength to the mattress, which was much needed in strong currents

and deep water. In addition to these iron rods, at certain localities where great strength was essential, twisted wire cables were placed on the mattress longitudinally, secured at intervals to the weaving poles by short wires. These mattresses were loaded at first next the shore, and then the head was heavily weighted so it would go to the bottom quickly.

The cost of grading varied from $3\frac{1}{3}$ to $2\frac{2}{3}$ cents per cubic yard, but the material excavated was sand, which was moved with great facility.

The engineer in charge estimated, after making daily observations for over a month, that to excavate 1 cu. yd. of earth took a fraction less than 1 cu. yd. of water under a pressure of 140 lbs, with a steam pressure of 80 lbs. and a vacuum of $26\frac{1}{2}$ ins. With a steam pressure of 80 lbs. it took 3 lbs. of coal per cubic yard of water thrown or earth excavated. He also estimated shovel grading at 30 cents per cubic yard, or ten times the cost of the hydraulic work. No change was made in the upper-bank work.

The cost of the protection work at Lake Providence Reach during 1882–1883 was $11 20 per lineal foot.

At Pilcher's Point a change was made in the manner of handling the mattress by the introduction of what was called a detachable mattress head, which was used in place of a mooring barge. Figs. 11, 12 and 13 show the head and details of construction. It was made of wood and consisted of two chords 20 ft. apart, connected by a series of cross diagonal bracing and a hog chain as shown in the drawings.

"The up-stream chord was 12 ins. wide by 30 ins. deep; the lower one 12 ins. wide by 19 ins. deep. These chords were 163 ft. long and had a camber of 6 ins., and were constructed of pine planks."

During the construction the mat was fastened to this head by lines which were sunk with it, being released by means of a lever and trips.

One mattress sunk was 152 ft. wide and 1 228 ft. long. The method of using the head was as follows: The sinking was commenced near the center, the mattress being loaded with rock both ways from this point until it had reached a depth of from 10 to 30 ft. Then two rock barges were lashed together and placed about 50 ft. from the head and allowed to drift over the partly sunken mattress, rock being thrown on the latter until it reached the bottom. Previous to the final sinking the depth of water over the outer edge of the mattress head was taken by means of a sounding line fastened to it. When the mattress had

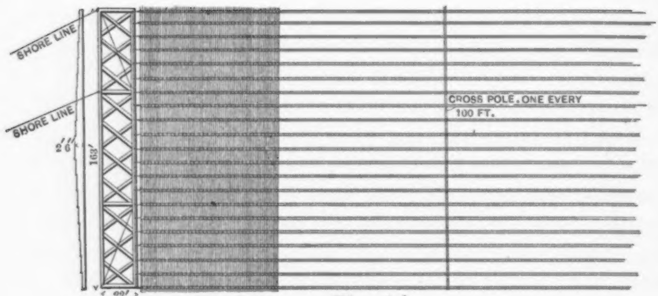
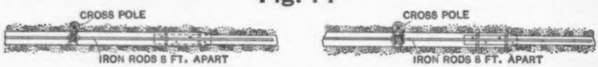


Fig. 11



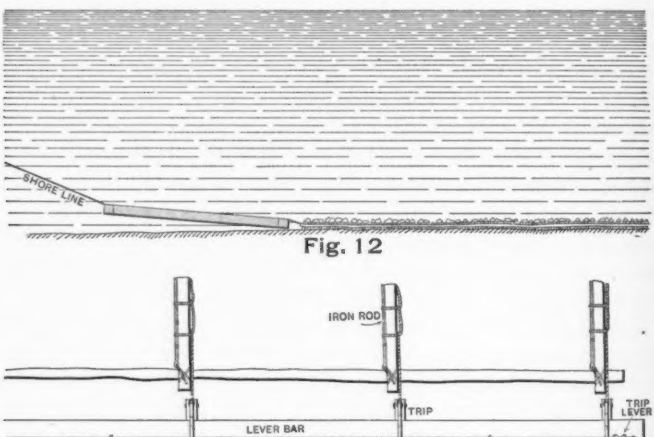


Fig. 12

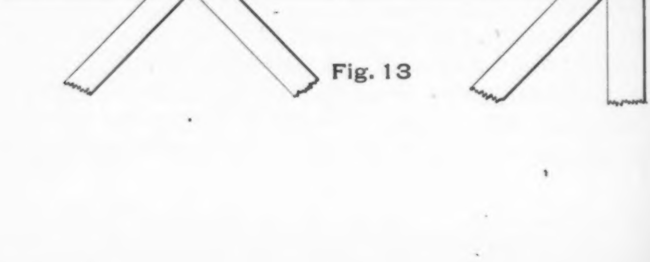


Fig. 13

sunk to two-thirds the entire depth, ten men, by pulling a line made fast to a ring at the end of a lever, tripped the triggers, releasing the head at once; the mattress sank with its load of rock to the bottom, and the head rose by means of its buoyancy to the surface. This mattress head was not generally adopted, the old method of mooring barges being adhered to, even to the present time.

The first work of revetment construction under the direction of the Mississippi River Commission at New Orleans was commenced in 1883.

Floating ways 400 ft. long were constructed by linking ten barges together, each 100 ft. long by 20 ft. wide. The woven mattress was used, the weaving poles having iron rods fastened to them. The poles and rods were 25 ft. long, the rods linked together at the ends making a continuous weaver. Two No. 8 wires were run through and across this mattress every 12 ft., and also heavy binding poles transversely every 25 ft.

After a very high stage of the river in the season of 1884, it was found that in many places in the long reaches of protected bank, the revetment both above and below the low-water line was too light to prevent the caving, and at some points the work was considerably damaged, necessitating changes in methods, strengthening and enlarging. Much unfinished work was destroyed because of lack of funds.

Work at Memphis in 1884.—One of the localities to suffer during the flood was the Memphis front. There the channel directly against the bank deepened materially, undermining the small mats sunk in former years. To prevent further damage and in order to replace the destroyed work, mattresses varying from 150 to 300 ft. in width were sunk and the upper bank graded and paved with stone.

The 300-ft. mat was constructed by placing two coal shells together end to end as a mooring barge, and two mattress barges also end to end on which to weave the mat.

In the construction of this 300-ft. mat two $\frac{5}{8}$-in. iron rods, ten $\frac{1}{2}$-in. iron rods and three $\frac{5}{8}$-in. wire ropes were used longitudinally. It was secured to the mooring barges by 1-in. and $1\frac{1}{4}$-in. manilla lines every 16 ft. across the head. Seven shackle lines from $1\frac{1}{2}$ to 2 ins. in diameter ran from the head to fastenings on the shore, and the mooring barges were held in place by nine lines $1\frac{1}{2}$ to 2 ins. in diameter

leading also to the shore above. Lines were placed diagonally across the mat every 100 ft. and fastened to the shore. This was one of the first very wide mattresses constructed, and notwithstanding its additional strength and the increase in fastenings, it was broken up in sinking. The engineer in charge of this work does not report the cost of this large mattress, but estimates for upper-bank revetment 100 ft. wide, $6 80 per square, and for all protection work, upper slope 3 to 1, bank work 100 ft. wide, and subaqueous work 150 ft. wide, $17 per lineal foot. During this same season on the Plum Point Reach the width of mattress was increased to 175 ft., one mattress being constructed of this width and 2 010 ft. long, another 175 x 1 750 ft., and a third 175 x 1 713 ft. Five wire cables were used in the body of these mats longitudinally.

The grading for shore protection was done with hydraulic power at 2 cents per cubic yard.

The distribution of material was as shown in Appendix A.

There were minor differences made in form and mode of construction of the revetment at certain localities to conform to special conditions and emergencies, which will not be mentioned.

The more important changes made in the old method of construction at Hopefield Bend opposite Memphis, in 1884, were the increase of mattress width to 150 ft. and the driving of a line of piles 8 ft. apart at about 5 ft. below low water, against which the shore edge of the mattress rested before it sank, not allowing it to slide up the bank on a rising water.

The mattresses were made stronger and thicker by weaving brush around but two poles, and then laying the tails over instead of weaving to the end, as shown in Plate III, Fig. 2. This allowed of much closer weaving, the tails being secured by binding poles wired down to the weavers, to which also transverse poles 8 ft. apart were fastened. Five ½-in. iron rods and two ⅝-in. wire ropes were run through the mattress longitudinally, and every 40 ft. transverse wire ropes or ½-in. iron rods were used, fastened to the piles at the shore end. On the upper-bank work wire rope was also introduced and much more stone ballast was used. The shore or upper-bank revetment was extended outside of the line of piles, lapping the mattress about 20 ft.

Spur Dams at New Orleans, 1884.—At New Orleans Harbor in 1884, a continuous mattress 400 ft. wide was broken up after sinking, and as

it proved a very difficult matter to place that type of revetment along the uneven line of wharves, some intact and some wrecked, the plan was abandoned and a new method adopted, viz., the placing of submerged spurs normal to the bank at intervals of 500 to 1 600 ft., generally at salient points. These spurs consisted of a woven mattress foundation 200 ft. wide, of the ordinary form then in use, with rods and cables to strengthen it, extending out into the stream about 350 ft. from the low-water contour, with a narrow cribwork filled with rock on the edge around three sides. When in place and ready to sink, this mattress was fastened to barges on three sides by double lowering lines 1-in. in diameter 16 ft. apart. Each lowering line passed around a timber head on the barge and led thence through the mat and up to a main rope which was carried to a capstan near the shore. All these lowering lines were fastened to the main line, which was manipulated by one man at the capstan.

The shore edge of the mattress was connected by iron rods with deadmen on the bank. Six large toggle lines were fastened to the upper end of the mattress, running thence to shore connections above. The method of sinking was similar to that before employed.

On this mattress on a line parallel with its up-stream edge and 70 ft. below it were sunk in the same manner six wooden cribs about $5\frac{2}{3}$ ft. thick, containing pockets in which rock was placed to sink them.* The bottom crib was 60 ft. wide, and the top one 22 ft. The completed cribwork was about 300 ft. long. The bottom crib was made the length required to fit the contour of the bank, the others varying in length in order to give the completed dike a top surface slope of about 3 to 1 from the low-water mark to the river-bed.

The cribs were made of sawed timber frames connected by long iron bolts and wooden posts fastened with wooden pins, between which and forming the body of the crib was placed willow brush, pockets being left in the construction in which to place the rock for sinking. In sinking the mattress about 7 lbs. of rock was used on each square foot of surface, the crib taking about 7 lbs. for each cubic foot of structure.

The mattress cost $7 60 per square, and the crib $3\frac{1}{2}$ cents per cubic foot. The total cost of one completed spur was about $12 525.

* The number of cribs in a dike varied with the depth of water, cross-section of banks, etc.

Results of Early Works.—By 1885 experience had demonstrated very forcibly the necessity of strengthening all the work of revetment or bank protection that had to withstand the continued force of the current and prevent the sloughing of the bank. Two very active forces to contend with were the seep water that undermined the slope, and the drift that accumulated at the head of the subaqueous work during construction, tearing out the fastenings by the increased pressure and doing great damage to the mat proper. The old mattresses were small and easily handled during construction, but when in place proved but a temporary protection, except at points where the material composing the bank was very hard and tenacious and the current and depth comparatively slight; whereas the new work offered great resistance to the current, especially while sinking, necessitating many more and very strong fastenings. This fact was not thoroughly appreciated until many accidents had occurred. Even during comparatively low water the drift falling into the river from caving banks gives trouble, and when a considerable rise finds a revetment party with an unfinished mattress in an exposed position, the danger from that source is very great. The drift accumulates under the mat head, forming a much greater surface of resistance to the current which has to be borne by the head lines, making the task of getting it to the bottom safely a very difficult one to perform.

At Memphis Harbor in 1885, the head of the mattress was strengthened by more and better iron chains, and by weaving through the mattress near its outer edge one 1½-in. and two 2-in. manilla lines. For a 600-ft. mat 250 ft. wide, sixteen head lines and three diagonal lines were used, nearly all being 2 ins. in diameter. At this time the engineers at all points began to advocate a greater strength of mattress and fastenings.

The methods adopted to prevent the sloughing of the upper bank and general destruction by seep water varied at different localities. When the water came through the bank in well-defined streams, tiles or drains of wood or stone were used. At one place a trench 90 ft. long by 4 ft. wide at the bottom and 16 ft. deep was dug and filled 6 ft. with rock, proving of great benefit.

The distribution of material in 1885 and 1886 is given in Appendix A.

By 1887 the general cost of finished standard bank protection was from about $25 to $30 per lineal foot, depending on the locality,

width of mattress, etc. This included all expenses of repairs and administration.

In this year on the Plum Point Reach the experiment was made of protecting the bank in a certain bend by detached pieces of revetment at intervals of about 500 ft. The results obtained and the discussion of this method will be given further on.

Work Done in 1887-88.—"Prior to 1873 the portion of the river bank at Memphis constituting the harbor front was comparatively stable. In 1876 it had receded 350 ft., and continued to cave at the rate of 100 ft. per annum." The next year, 1877, Congress directed that a survey be made and a report submitted. The plan adopted was for protection by revetting the bank with willows ballasted with rock. This work was carried on without much change in bank line up to 1884, when the new and more substantial revetment was adopted. About that year a complication of changes took place in the river in that vicinity. Hopefield Bend Point was caving away rapidly, thus throwing the resultant of greatest pressure lower on the Memphis side, relieving much of the bank already revetted and threatening the paved levee and the landings below. By 1887 the greater part of this front had been protected, but the continued recession of the Arkansas side, and the accumulated energy in the water passing along the lower revetment on the city front, augmented the caving still further down the river, where the bank conditions are very different from those existing above. Instead of a sloping paved levee from low water to high, the bluff rises nearly vertically to the height of about 100 ft. Here spur dikes somewhat similar to those used at New Orleans were substituted for the continuous revetment. The spurs were placed about 500 ft. apart between centers and reached from the foot of the bluff to the bed of the river.

These spurs were constructed partly by funds contributed by the city of Memphis and partly by Government appropriation. The mode of construction in its general features was similar to that in use at New Orleans. The foundation mattress and cribs, one placed on another, reaching the required heights and inclination, were sunk in practically the same manner. A more minute description of the method of spur construction is given under the head of "Details of Greenville Dike Construction," where the author was in local charge and the work was practically the same as that at Memphis.

In 1888 the whole system of revetment at Memphis comprised a

bank protection of willows and stone about 2 miles in length, and it was estimated that 1 mile more would be required to complete the work. In Hopefield Bend, opposite and above Memphis, it was estimated also that 1 mile farther down stream would have to be protected to hold Hopefield Point, in order to control and guide the channel of the river in the desired direction.

The distribution of material and cost of work during the season at Hopefield Bend and Memphis Harbor are shown in Appendix A. The cost of the Hopefield Bend work from September, 1887, to January, 1888, subaqueous mats and upper-bank revetment combined, including administration, repairs to plant, towing, etc., was $4 44 per square covered.

At Greenville, Miss., a similar project to that undertaken at Memphis was adopted. The dikes were constructed partly by funds contributed by the town. Ten dikes were built, nine of about the same form as those used at Memphis, and one having cribs formed with frames of 3 x 4-in. sawed gum lumber, in lengths of 8 and 16 ft., fastened by ½-in. bolts at each intersection. Here in constructing the upper-bank revetment the old method of carrying and distributing rock on the willows by hand was abandoned, and a carrier devised to take it from the barge and distribute it along the slope. It consisted of a pile-driver placed outside of the stone barge, and a wire rope 1⅛ ins. in diameter, fastened to its leads and passing thence to and over a trestle about 16 ft. high on top of the bank, anchored to a deadman or stump 40 ft. back. A box was suspended from a traveler which ran on the wire rope and was actuated by the hoisting machinery on the driver, and unloaded by a trip line manipulated from the ground.

On this work, the upper portion of the upper-bank revetment had two layers of brush instead of one as had been the custom.

The ten dikes constructed during the season cost, including towing, $101 011 03, or about $10 101 10 each. About 5 000 ft. of bank was thus protected, at a cost of about $20 20 per foot.

At New Orleans Harbor the methods of dike construction were modified in order to get a more substantial form of protection. The iron rods in the cribs were dispensed with and replaced by wooden stanchions, the thickness of the cribs was increased to 6 ft., the depth of rock pockets was reduced to about one-third the thickness; the cribs were loaded as heavily with rock before being lowered to the

bottom as the lowering lines would stand, and no rock was thrown on them after being placed on the mattress. The cost of the New Orleans cribwork was 4 57 cents per cubic foot, excluding care of plant, etc. One mattress cost $7 54 a square, and another cost $9 11. The rock for this work cost $4 11 per cubic yard.

Work Done in 1888-90.—Up to the year 1888 the purpose for which bank revetment had been used was, as has been demonstrated, the protection of valuable property, wharves, landings, warehouses, etc., and maintaining the river in certain reaches within given limits of curvature and position with reference to shoals and bends above and below, in order to regulate low-water depths, etc. .

In 1888 it became apparent that unless some action was taken to prevent the caving in some of the lower bends, cut-offs would occur, producing very radical changes in the regimen of the river for many miles above and below. To prevent this occurring at Ashbrook Neck, the upper bend of the peninsula was revetted with the standard type of continuous mattress and upper-bank work. Also at Lake Bolivar, where the bank was receding gradually toward the large inland lake, and the river threatening to turn a portion of its water into the back country, the formation of the outlet was prevented by the use of continuous mattress protection.

This year the mattress work at Plum Point Reach was 200 ft. wide, and was held out to near the low-water line by piling; the upper bank was graded to a more gentle slope. On a portion of the work the brush was not placed on the upper bank, and in its place from about the 13-ft. stage, where the connecting mat ended, to near the top of the slope, stone paving was laid on the bare ground to a thickness of 10 ins. No cost is given of this first paving.

At Hopefield Bend Point and Memphis, the river continued to creep to the west and south, destroying the former point and training the thalweg toward the bluffs. It had been the purpose of the engineer in charge to allow this action to continue until the channel was in the required direction, then to check the caving on the Arkansas side with strong continuous revetment, which, when accomplished, would maintain the best depths and velocity of water along the Memphis city landing. When the time came for putting a stop to the caving at Hopefield Point, funds were not available, and the project could not be fulfilled. The point caved nearly half a mile too far before means

were obtained to check it. By that time a bar had formed at the upper end of Memphis Harbor which threatened to obliterate completely a large portion of the city landing. It is justly claimed that this filling in the upper end of the harbor is not due to imperfect methods or appliances nor to faulty engineering projects, but simply to not having the money to carry out the plans as formulated.

In 1888, 4 105 ft. of continuous standard revetment was placed in Hopefield Bend, a total width of 335 ft., the subaqueous mat being 196 ft. wide, the grade of the upper bank 3 to 1, and the upper-bank revetment 139 ft. wide.

The entire revetment, including mat and bank work, administration, care of plant, repairs, towing, etc., embracing an area 4 650 ft. long by 338.6 ft. wide, covering 15 749 squares, cost $4 75 per square.

At Bolivar Landing in 1888 the mattresses and upper-bank revetments were similar to those used at other points. The former varied in length from 224 ft. to 1 100 ft., and in width from 180 ft. to 250 ft. The cost was $91 341 78, or $6 95 per square, and $21 24 per lineal foot. Including all charges against this work the cost was $9 26 per square, or $28 31 per lineal foot. This latter would be reduced somewhat by allowing for rock unloaded on the bank, but not used, and the towing charges against it.

At Greenville Harbor the dikes, as before stated, were 500 ft. apart, leaving between them an unprotected space of about 300 ft. The foundation mats were about 200 ft. wide, extending out into the river from 375 to 415 ft. At first the dikes caused the deep water to move out toward the center of the river, the depth being increased in the channel. The 30-ft. contour moved out 225 ft. and some deposit showed on the cribs. At the upper end of the system considerable caving had taken place. To check it 706 ft. of continuous revetment was placed 250 ft. wide; also for 700 ft. below the mattress-work the bank was graded, and 250 ft. of it covered with brush. In the interval between some of the dikes sloughing had occurred which had to be repaired by mattress work.

Owing to the tenacity of the soil and the strong work placed at Delta Point, Vicksburg—about 10 000 lin. ft. in 1882-1883—but little repair had been necessary up to 1889, when a small portion of the upper bank was graded back and a revetment placed on it, with diagonal layers of brush, well covered with rock.

At New Orleans the old work placed prior to 1884 was practically intact in 1889. After 1884 the spurs had moved the deep water away from the bank 100 ft., with no increase of maximum depth, as at Greenville. The depth of water at one point where it was proposed to continue the construction of the system of dikes was found to be 150 ft. In order to make the spur conform to this depth and have the required surface elevation, it was necessary to build the cribs 450 ft. long and the mattress longer. The ways not being of sufficient length, a supplementary mat was constructed and placed at the outer edge of the woven mattress, being over 100 ft. wide. This supplementary mattress was made on the plan of those used in the sill dams at the head of the Atchafalaya, mouth of the Red River, and somewhat similar to the old pin and frame construction described in the beginning of this paper. It was made of 2 x 4-in. scantling frames, placed 8 ft. apart. Top and bottom frames, with brush between, were joined together by 2-ft. stanchions, fastened in sill and cap by a 6-in. wire nail and a ¾-in. pine treenail. The willows on the bottom layer were nailed to the frame to strengthen the mat and keep it from pulling apart. This mattress was sunk 300 ft. from the shore in about 153 ft. of water and in a current of about 5 ft. per second. An additional lowering barge had to be placed outside of those used for the main mat; guide chains from anchors formed of loaded kegs were used also to insure accurate sinking. The mat was loaded and sunk in the customary manner. It cost \$9 56 per square; the woven mat, \$6 39 per square. The cribwork placed on these mattresses cost 4 cents per cubic foot. This dike when finished was the largest submerged spur ever constructed on the Mississippi River, and probably in this country.

In the autumn of 1889 the work of protecting the bank at Hickman Harbor, Ky., began. Hydraulic grading and the usual method of bank revetment were used. The first mattress was sunk on a projecting point, necessitating the use of anchors in order to get a correct lead for the head lines. The Chinese anchors used, the positions of the barges, etc., are shown in Figs. 14, 15, 16 and 17. The mattresses were 300 ft. wide by 750 ft. long, connected by shore mattresses to the upper-bank revetment. The cost of the work complete was \$24 77 per lineal foot.

At Plum Point in this same season all the connecting mats were dispensed with at some points, the mat being held well into the bank,

and a shore revetment constructed connecting with it before it was sunk.

At Columbus Harbor, Ky., this season, crib dikes were constructed, consisting of the ordinary woven mattress carpet, and a single crib, 28 ft. by 8 ft., extending from the upper edge of the mattress to a point 240 ft. beyond the low-water line. The longitudinal axis of the crib was about 12 ft. above that of the mattress.

The cost of the work was 4 cents per cubic foot, $6 70 per square, and $22 65 per lineal foot.

During the season the improvement of Helena Harbor was also undertaken. The project contemplated the placing of 600 ft. of continuous

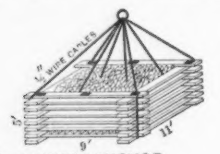


FIG. 14. CHINESE ANCHOR

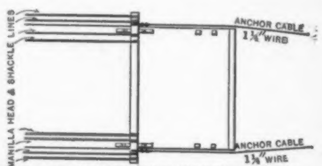


FIG. 15. PLAN OF ANCHOR BARGE AT "L"

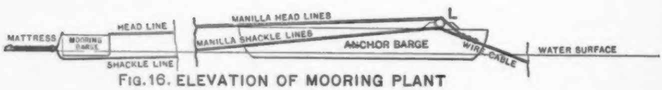


FIG. 16. ELEVATION OF MOORING PLANT

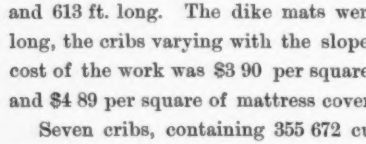
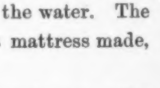


FIG. 17.



revetment and five spur dikes. The mattress work was 228 ft. wide and 613 ft. long. The dike mats were about 200 ft. wide and 330 ft. long, the cribs varying with the slope and depth of the water. The cost of the work was $3 90 per square of subaqueous mattress made, and $4 89 per square of mattress covered.

Seven cribs, containing 355 672 cu. ft., cost 4.4 cents per cubic foot.

In 1889 steel cables were used for the first time, with shackles or toggles as head lines, in place of manilla ropes. Their use had been advocated, but the difficulty of handling them caused engineers to doubt their value from an economical standpoint. Their great superiority over

the manilla line was not so much in their strength as in their durability and the fact that, as compared with manilla, they practically remained of uniform length under the strains produced in mattress sinking. The manilla ropes required a constant taking up and adjusting in order to maintain an equal pressure, whereas the steel cables could be placed at once, and the strains readily distributed throughout the system of head lines, necessitating but little change or further work. This introduction of steel cables as head lines was a very important improvement in mattress construction, reducing to a minimum the chances of loss where a sufficient number of strong shore fastenings were used. A new manilla line when subjected to great strain will stretch far beyond the limit of one that has obtained a permanent set by continued use, and when used among older head lines it produces a lack of unison in the system which is often followed by disaster.

At first the mooring barge cables were fastened to wooden cavels, but it soon became apparent that these would not have sufficient strength, so they were made of cast iron. The shore fastenings were generally deadmen, with keys or timbers 18 to 24 ins. in diameter. At this time it also became apparent that much of the loss by sloughing down of the bank was due to the fact that it was not graded to a light enough slope. Of course, in many places to overcome entirely the tendency to slough, it would be necessary to grade to an exceedingly gentle slope, the angle of repose of wet earth, but this was not advocated, it being deemed advisable to grade to about 4 or 5 to 1 only, thus reducing to a practical minimum the sloughing tendency. The additional cost of flattening the slope was compensated for by leaving from 8 to 10 ft. at the top of the bank vertical, or with its natural inclination prior to grading. It was found that little or no caving took place at the crest when the rest of the bank was protected.

It was suggested that planting Bermuda grass on this upper slope would be advantageous, but this was found to be a poor expedient as a protracted high-water season would kill it. Willow plantations have been more successful, but they add very little strength and cause but slight deposit in the rapid current along the protected bank.

On the Lake Providence Reach, Louisiana Bend, the upper bank was first graded to a slope of about 4 to 1 and then paved with rock to a thickness of 10 ins. The rock was carefully laid by hand directly on

the bank, no willow revetment being placed under it as a foundation, as had been formerly the custom.

Where the upper bank had been previously revetted with willow brush ballasted with stone it was found that in about four years the willows above the low-water line rotted out, necessitating an entire renewal, which meant the removal of the work and redressing of the bank. It was expected that by placing the rock directly on the bank this would be avoided, and by making it thick enough it would prevent abrasion. Where the willow revetment is constantly under water it does not deteriorate except from the mechanical action of running water; whereas, if it be exposed to the air and sun it disintegrates in from three to four years. By thus dispensing with the upper-bank willow work, the first cost of revetment was considerably increased, but it was hoped that its greater permanency would more than compensate for the extra expense incurred.

The mattresses on this work were from 300 to 342 ft. wide and sunk in lengths of from about 500 to 1 000 ft.; they were built and sunk as on the upper river, against a line of piling.

Shore mattresses lapping the main mattress were used when necessary. The main mattresses were strengthened by weaving ⅝-in. wire cable longitudinally through them, spaced 16 ft. apart, and placing holding-in cables every 16 ft. across them. The latter were fastened to deadmen on the shore, and tightened by tackle blocks after the upper slope was graded.

The grading here was done after the subaqueous mattress was sunk. The engineer in local charge, Arthur Hider, M. Am. Soc. C. E., claimed this to be bad practice, giving among others the three following reasons for grading the bank before building and sinking the mattresses.

First.—The graded bank allowed the holding-in cables to be placed permanently, with the proper strain and position to insure the mattress sinking in the desired place.

Second.—By dispensing with the piling the mattress would sink on a uniform slope, not being canted up on steep uneven ground.

Third.—The rock could be unloaded directly on the finished slope, not necessitating double handling.

The labor cost of the work was \$71 679 16 for 27 367 squares, or \$2 62 per square.

At Greenville in 1890 the spur dikes were intact, but the current

was attacking the bank at the upper end of the system, threatening its destruction. The dikes could not be considered entirely successful. At some points the bank in the unprotected intervals between the cribs had caved badly. At some the 30-ft. contour had moved out, but at others the reverse was the case, while in much of the improved reach the outer ends of the dikes had been undermined. The amount of deposit between the dikes varied at different seasons, with the change in the stage of the water and its height.

In 1889 the author added two dikes at the head of the Greenville system, and as they were built in a practically similar manner to those sunk in previous years and those adopted for other harbors, a description of the details of construction will cover all the partly submerged spur types in use on the river.

Details of Greenville Dike Construction.—The dikes consist of cribs made of willow poles and brush fastened by wire and spikes, having pockets formed in them in which rock is placed to sink them, and having for a foundation a mattress woven and sunk in the manner heretofore described. They are placed normal to the bank line and 500 ft. apart, and reach out beyond the deepest water in the channel next the shore. The purpose they are expected to serve is the protection of the bank immediately at the point they occupy and the indirect protection of the intermediate spaces by deposit, due to the eddy and dead water formed by their position relative to the swift current of the river.

After an accurate hydrographical survey of the locality to be improved, a mattress 290 ft. long by 290 ft. wide extending about 50 ft. beyond the deepest water was constructed on floating ways, of willow brush and poles, wire and spikes, and launched into the river as woven. After being fastened by cable shackle lines to the shore above, it was ballasted and then sunk in the usual manner.

The mattress was the foundation for the main body of the dike, which was formed of cribs. The dimensions and general form of cribs were governed by the profile of the bank immediately at the point where the dike is located. The dike under consideration contained but two cribs, the lower one 212 ft. long by 32 ft. wide and 8 ft. deep, of uniform section; the upper one, 170 ft. long, 16 ft. wide and 8 ft. deep. The longitudinal axis of the cribs was 90 ft. below the up-stream edge of the mattress. The dike was finished with as nearly a uniform surface as possible, having a slope of 4 to 1 from the river end to the top of

the graded bank. The cribs were each right rectangular prisms in general form. Where four or five were required, the top one was 16 x 8 ft., the next 32 x 8 ft., the next 48 x 8 ft., and so on, the last one sometimes being constructed to conform to the irregularities of the bottom, but having a uniform top surface.

The details of crib construction were as follows:

A framework of poles and willows was laid on the floating ways on which the mattress was constructed, in 8-ft. squares, to the required length and breadth. On this frame layers of brush, both longitudinal and transverse, were placed, and on these another frame similar to the first, then other layers of willows followed by a frame, and so on until the crib had attained a thickness of 3 ft. Then the frames and intermediate layers of brush were thoroughly sewed together with No. 12 wire and 9-in. spikes, wire being left projecting far above the last frame to fasten the lower to the upper cribwork. When the construction had reached this stage the partly finished crib was launched from the mat barge and placed over the mattress on which it was to rest. It was then fastened by lines to the mooring barges, which held it in place, and also connected with the shore by shackle lines leading well up the river.

At the intersections of the frame poles, 8 ft. apart, upright posts 9 ft. high were then securely fastened, and to these, as well as to the lower frame, the crib was built, pockets or compartments being formed in each 8-ft. square, the shape of an inverted frustum of a pyramid, by dropping back one pole as each layer of brush was laid above the bottom 3-ft. foundation. When finished the crib was 8 ft. deep, with pockets 8 ft. center to center, about 5 ft. deep, and each capable of holding about 3 cu. yds. of loose rock. The whole crib was securely held together throughout with spikes, wire and $\frac{5}{8}$-in. cables. The process of sinking was practically the same as in the case of the mattress. After the crib was securely fastened to the bank by cables placed carefully over the mat in the desired position, and after being checked up well by slip lines to the mooring barges, rock was thrown into the pockets until they were filled. When the weight had considerably more than overcome the buoyancy of the structure, the strain on the lines being very great and the crib in a sinking condition, then the slip lines were rendered slowly, care being taken to keep the strain uniform until the crib settled in its place on the mattress. In the case

of the second crib, it was built 16 ft. narrower, as before stated, and sunk in the same manner on top of the first one, thus forming a sill 16 ft. high.

After the mattress was constructed and sunk, before the cribs were started, the portion of the bank above the mat and water line was graded to a slope of 4 to 1, preparatory to covering it with a revetment of willow and stone, which was connected with the submerged mattress.

The grading was done with a sluice as before described.

After completing the grading, the revetment was laid; first a framework of poles in 8-ft. squares, then two diagonal layers of brush placed on it, then another framework corresponding to that below, and the entire mass tied together securely with wire and spikes. On this, stone was laid close enough to hide the brush.

When the revetment was finished and the mattress and submerged cribs sunk, the upper end of the latter was joined to an upper-bank crib which carried the regular slope of the top surface of the dike to its intersection with the upper bank.

This upper-bank crib, though constructed on the ground, was in form similar to those made on the ways, and formed but the continuation of the subaqueous work.

The brush for the work cost per cord....	$1 27½	and	$1 09
The poles, per cord....................	1 47½	"	1 48
The rock, per cubic yard........	1 50	"	1 95

All of the material was delivered, the brush and poles at the contractor's camp, and the stone at the work on board of government barges, for that price. The total money expended in building two dikes was $24 037 76. More cables and other materials were used in these dikes than had formerly been the custom. The field cost and material used in their construction are shown in Appendix A.

The total cost of the dike was: Foot mat, $3 830 49; crib No. 1, $1 698 73; crib No. 2, $871 55; revetment, $3 167 82; shore crib, $92 69; total field cost, $9 661 28. The gross cost of the entire work was considerably greater than the net cost as shown in this dike would indicate, because of the difficulty of obtaining good labor during that season, the run of drift, the remoteness from the base of supplies, and the excessive amount of material used in the first dike constructed, the cost per unit being much in excess of that of the second dike.

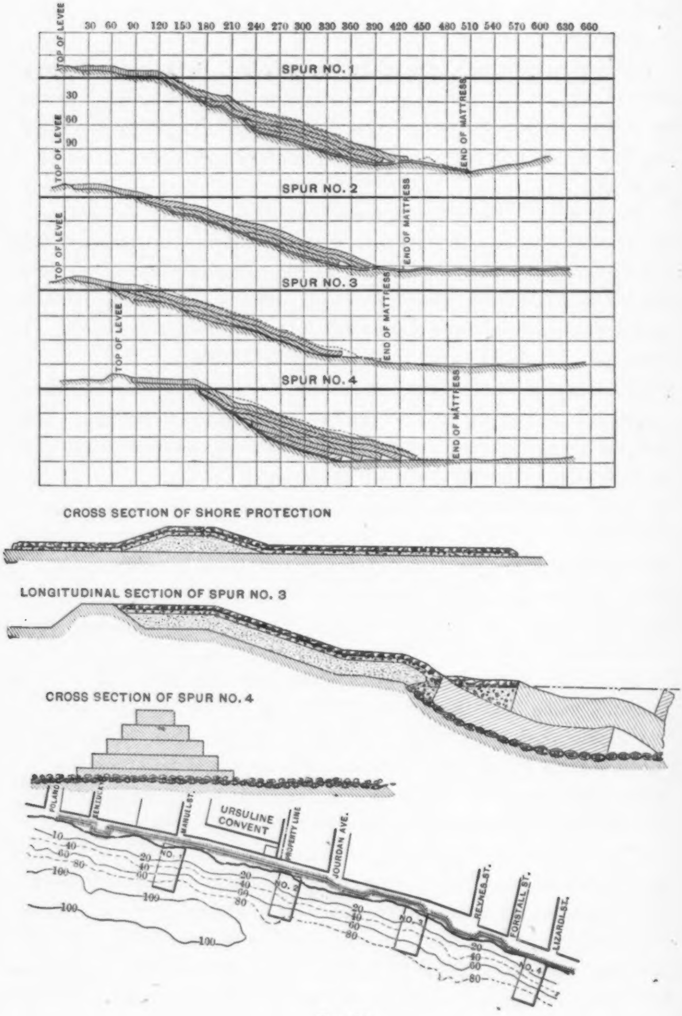

30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660
TOP OF LEVEE
SPUR NO. 1
END OF MATTRESS
SPUR NO. 2
SPUR NO. 3
SPUR NO. 4
CROSS SECTION OF SHORE PROTECTION
LONGITUDINAL SECTION OF SPUR NO. 3
CROSS SECTION OF SPUR NO. 4
URSULINE CONVENT
PROPERTY LINE
JOURDAN AVE.
MANUEL ST.
REYNES ST.
FORSTALL ST.
LIZARDI ST.

Fig. 18.

The cost of continuous repair revetment work at Bolivar Landing during the season of 1889 was $10 68 per square.

New Orleans Spur Dikes.—In 1890 the construction of spur dikes at New Orleans was continued. There the dikes were much larger than at other points. In that portion of the river, this particular kind of bank protection is especially well adapted to the existing conditions. As before stated, the small variation in elevation of water surface, as compared with points above Red River, the less rapid caving and the more uniform flow, all produce a condition favorable for the adoption of that method.

One of the dikes built this season was the largest ever placed in the river. It contained about 3 400 cords of willows, 80 000 ft. of lumber, 2 000 tons of rock, 5 500 lbs. of wire, 60 kegs of nails and spikes, and 8 000 lbs. of iron rods and chain. Its length was 430 ft., and height 60 ft. The depth of the water at its outer edge was 152 ft.

The dikes were constructed of sawed lumber frames in place of rough willow pole frames, as in the upper-river work, and they were formed of cribs in some cases five and six tiers high. Fig. 18 shows cross-section of some of these spurs of 1890.

This season a departure was made from the plan before adopted, which changed the dikes from purely submerged structures to a form somewhat similar to those used at Memphis and Greenville. This consisted in carrying the dike above low water by connecting it with an earthen levee with a crown of 10 ft. and slopes of 3 to 1, the bank being first graded to a gentle slope. On this levee rock was placed to a thickness of 9 ins., forming a pavement covering the levee and extending 20 ft. above and 50 ft. below it (see Fig. 18).

The average field cost of these dikes in 1890, not including administration, repairs, etc., was $7 15 per square for mattress work and 3.6 cents per cubic foot for cribwork. These spurs average 1 000 ft. apart.

The standard revetment by this time had become generally adopted, and consisted of continuous revetment and dike construction. The standard revetment as used in 1890 in the upper districts is described in detail in the report for 1891 of the Chief of Engineers of the United States Army. As the woven mattress and willow upper-bank revetment had reached its most perfect form, and was shortly to be replaced by an entirely different kind of willow work for the subaqueous portion and paving of the upper bank, a description of it will

be given as illustrating the highest development from the crude methods of 1882 of this type of protection work.*

Construction of Standard Bank Protection, 1890.—After staking out the top of the slope to a grade of 4 to 1, measuring from the low-water line, the bank is cleared of all trees and trash 50 ft. back of the top.

When the clearing has been carried ahead a sufficient distance, one or two hydraulic graders are started and the bank sloped in the manner heretofore described. "After grading, the bank is dressed by hand, all holes being filled up with brush and dirt."

Either after or before grading, the latter being preferable, all snags are removed from the bank in the reach in which the mattresses are to be placed. Two methods are resorted to, blasting and pulling with steamboats. The snag boat method is less expensive, but more satisfactory if followed by the submarine diver.

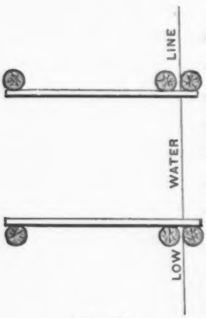


FIG. 19.

When a considerable reach of bank has been cleared, the snags removed, and the grading completed, an abutment is constructed consisting of two piles driven 15 ft. apart and parallel with the bank, and 10 to 15 ft. inside the low-water line. Out from and directly opposite these, at the low-water line are driven two clusters, with two piles in each cluster (see Fig. 19). An inclined brace connects each cluster to the pile behind it. These piles are left about 10 ft. above medium low water. The braces are sawed off flush with the outer face of the twin piling, to allow for mooring barges.

On this abutment, when the mattress barges are swung into place, the inside edge of the mooring barges rest, and are held out to the required position. Below this abutment, on the zero line, single piles are driven 100 ft. apart for the full length of the required mattress, the top of these piles being left, as in the case of the abutment clusters, about 10 ft. above the medium low water. By means of this piling the mattress is kept over the zero line during a limited fluctuation of the water surface, while being constructed and sunk. After the mattress is on the bottom, all these piles are cut off or pulled out, as they would otherwise form obstructions to navigation.

* See the paper by Mr. A. G. Nolty, assistant engineer, on details of construction of bank protection works, as practiced at Plum Point Reach in 1890. "Report of the Mississippi River Commission," 1891, p. 3606.

"While the abutment is being constructed two mooring barges lashed end to end are placed alongside of the bank above the abutment. Outside of these barges, parallel with them and with the ways touching the gunwale, is placed the mattress or weaving barge." The head lines connecting the mooring barges with deadmen or trees on the bank consist of six wire rope cables, the up-stream one $1\frac{1}{4}$ ins. in diameter, the next two $1\frac{1}{8}$ ins. in diameter, and the last three 1 in. in diameter, as shown in Fig. 20. These cables have an eye spliced in one end, which is used for fastening them to the cavel of the mooring barge. On the up-stream edge of the latter the timber heads have heavy iron bands forming eyes through which the eye of the cable is brought and fastened by a $1\frac{1}{4}$-in. iron bolt.

While the mooring lines are being run, the head of the mattress is under construction.

"Hardwood poles, as large as can be conveniently handled by a gang of men and reasonably straight, are laid in two lines on the ways over and parallel to the inner gunwale. These poles lap each other 10 to 15 ft., the two lines breaking joints. Where they lap they are spiked together with $8\frac{1}{4}$-in. spikes every 2 ft., and also tied together with No. 12 galvanized wire at intervals of 10 ft., except at the laps, where two ties are made. This line of poles is equal in length to the width of the mattress."

Upon these poles, at intervals of about $7\frac{1}{2}$ ft. and at right angles to them, the butt ends of the weaving poles are securely fastened with two 8 x $\frac{1}{2}$-in. spikes and a lashing of No. 12 wire. Upon these latter another set of poles similar and parallel to the first are placed, spiked and wired, and the whole head thus formed securely fastened with wire.

"The weaving poles are live willow or cottonwood brush reasonably straight, and 4 to 6 ins. in diameter at the butt, and from 25 to 30 ft. long.

"To facilitate weaving all knots are trimmed off and the top and bottom quickly smoothed with a draw knife. A cable made of eight strands of No. 12 wire is fastened around the head of the mat at every third weaving pole and run up alongside of it, being fastened thereto by two staples. These cables are 24 ft. long, with an eye in one end, to which, after each shift of the mat, a new length is looped in weaving. Ten continuous cables are thus formed in the mat, greatly strengthening it longitudinally."

While the head is being formed the mattress head lines are being run out, and when it is finished they are fastened to it. These lines are five in number; one near the outer edge of the mattress, $1\frac{1}{8}$ ins. in

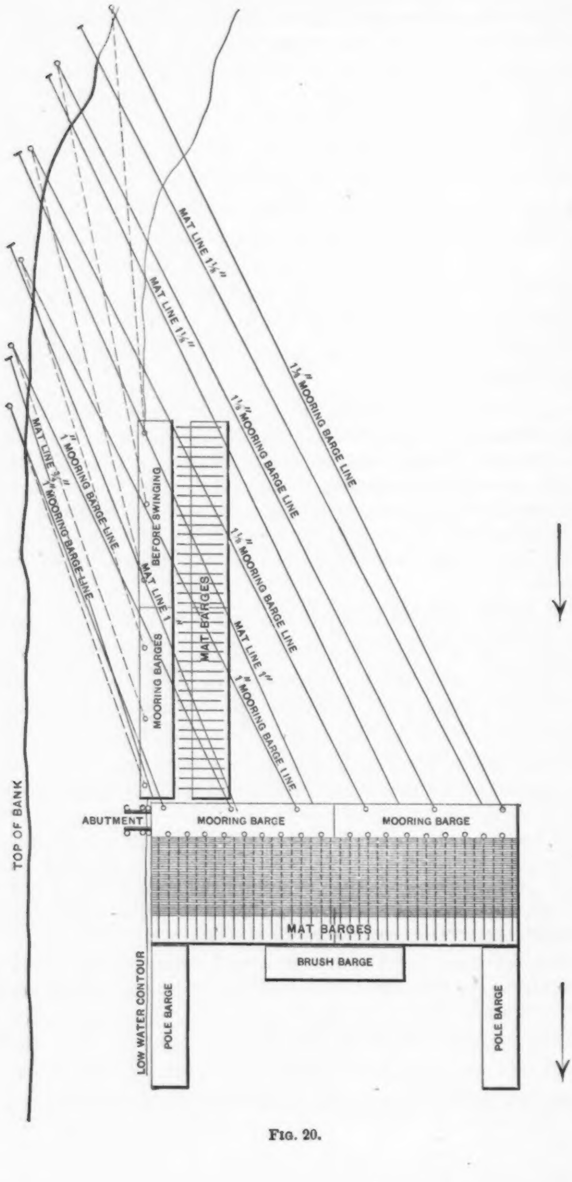

MAT LINE 1⅛"
MAT LINE 1⅛"
1⅛" MOORING BARGE LINE
1⅛" MOORING BARGE LINE
1⅛" MOORING BARGE LINE
BEFORE SWINGING
MAT LINE 1"
MAT BARGES
MOORING BARGES
MAT LINE 1"
1" MOORING BARGE LINE
MAT LINE ¾"
1" MOORING BARGE LINE
1" MOORING BARGE LINE
TOP OF BANK
ABUTMENT
MOORING BARGE
MOORING BARGE
MAT BARGES
BRUSH BARGE
LOW WATER CONTOUR
POLE BARGE
POLE BARGE

FIG. 20.

diameter; then, at equal intervals to the inner edge, one, 1⅛ ins.; two, 1 in.; and one ¾ in. They lead from shore fastenings, as in the case of the mooring lines, and pass under the mooring barges, being fastened to the mat-head loop by a pin shackle. The mat-head loop is made of 2-in. manilla rope fastened to the head and running back into the mat at least 25 ft.*

"The brush used for weaving is live straight willow of any length above 25 ft., and from 2 to 4 ins. at butt.

"A full complement of men for a 200-ft. wide mat is 54, under a foreman, divided into three equal gangs, each under a master laborer. Each gang consists of five men on brush barge passing brush to weaving party, twelve men in weaving party, and one man on mat mauling brush tightly into place as the weavers push it down. Each gang builds one-third the width of the mat.

"The brush barge is placed outside (below) the mattress barge about midway between the two ends, and a barge loaded with poles is hung to each of said ends.

"A coil of 2-in. rope is placed on each end of the mat barge, and the free end fastened to a timber head on the mooring barge. The skids on the ways are well slushed with axle grease or tallow, to reduce the friction in weaving and launching. In a 200-ft. wide mat, 27 weaving poles are used. In weaving they are close to the skids or ways and at the upper end rest in brackets, bolted to the upright posts on the mattress barge.

"The brush is passed from the brush barges to the weavers who work in pairs, and is woven by them into the mattress. The butts are placed over one weaving pole and 2 ft. beyond, being woven at the other end over the next pole, under the third, over the fourth, and so on, the light ends being always left on top."

A strip 5 ft. in width is woven thus, in the next 5 ft. the butt is reversed, and so on, the butts changing directions every 5 ft. When the mattress is woven to within 2 ft. of the end of the poles, giving about 22 ft. length of mattress, it is swung in position with the accompanying barges.

The entire floating plant is swung on two lines, a 2-in. manilla rope on the outside and a 1½-in. manilla rope on the inside of the mooring barges, having one end fastened to the shore (see Fig. 20). The head lines on the barges and mattress are slackened until the barges take a position nearly normal to the shore, with their inside edge resting on the pile abutment.

* The number and strength of lines depend on the velocity of current, the stage of water and amount of drift running. In the lower districts more fastenings, as a rule, are used than as shown above.

" The slack in the mooring barge cables is now taken in from the bank and the strain equalized. They are then fastened permanently with clamps furnished for that purpose, the mattress head lines being treated in the same manner."

To prevent the mattress sliding too far when launching a finished shift, five 1¼-in. manilla lines 100 ft. long are fastened equidistant on the mat, and pass underneath it to cavels on the ways. They are slackened off in launching. Their fastenings on the mattress can be shifted to economize rope.

"The slip lines are 1¼-in. manilla rope about 125 ft. long, there being 18 to a 200-ft. mat. Each has an eye large enough to pass over a timber head. This eye is placed over one of a line of timber heads on down-stream edge of mooring barge, the free end being passed under the head of the mat and up again on its down-stream side, and then hauled taut and fastened on its timber head. The mattress head is thus hung in 18 slings. When these slip lines are all adjusted the mat is further launched until the down-stream edge is over the up-stream gunwale of the weaving barge. The office of these lines is two-fold; they hold the head of the mat up, preventing the current and drift from forcing it under, and they are used to lower it to the required depth in sinking.

"When one entire shift (about 22 ft.) is launched, a new set of weaving poles is spliced to the projecting ends of the first set, the butts of this set being spliced to the tops of the preceding one, after having been pushed into the mat about 3 ft., thus making a lap of 5 ft. Two 8 x ¼-in. spikes and two wire lashings are used to fasten each splice. This is continued as described to within 2 ft. of top of second set of poles, when another launch is made, and so on, until the full length of the mattress is obtained."

The mooring barges were swung to a position not quite normal to the shore, but as the mattress is constructed, the greater pull on the outside lines and careful adjustment of all the strains brings them into the perpendicular.

" As soon as three shifts of mat are launched, the construction of a top grillage or framework is begun, consisting of a line of poles laid over the weaving poles and parallel thereto, lapping each other, butts to tops, from 6 to 8 ft. and wired to the weaving poles every 4 ft. by lashings 2 ft. long, made of two strands of No. 10 wire; transverse poles 8 ft. apart for the first 100 ft., and thereafter 16 ft. apart are placed in similar manner and fastened to the longitudinal ones at the intersections by 2-ft. lashings, made of four strands of No. 12 wire. This grillage is for the purpose of forming cribs, to retain the stone on steep slopes, and it also strengthens the mattress. The first set of

transverse poles along the inner edge are hardwood, are only 8 ft. apart throughout the length of the mat, and are used to connect the shore mat to the river mat.

"The construction of the shore mat, which is expected to progress with the river mat, is carried on by a gang of from 30 to 40 men under a foreman and one master laborer. The space to be spanned in building the shore mat varies with the stage of water from 0 to 60 ft. In its construction a small flat boat is generally used from which to work. Hardwood poles of the size of the weaving poles are lashed to the river mattress with three No. 12 wire lashings 2 ft. long and spiked with two 8 x ¼-in. spikes. Willow or cottonwood poles are spliced to these until they reach up the slope about 40 ft. Alongside and fastened to each of the hardwood poles is a cable made of eight strands of No. 10 wire, one end of which is fastened to two of the adjacent weaving poles, and the other to the willow poles extended on the slope. Upon the transverse poles are laid longitudinally willow or cottonwood poles 8 ft. apart, beginning with the first set about 4 ft. from the edge of the mat. The latter poles are wired to the former at their intersections with lashings of No. 12 wire 2 ft. long. The longitudinal poles are carried on lines 8 ft. apart up to the top of the slope, and on their lower side, 8 ft. apart, are driven stakes 2½ ft. above the ground, to the top of which is fastened loosely a lashing of No. 12 wire 2 ft. long, whose bight has been first passed under the pole. These stakes are used down to the pole nearest the water edge. Upon this framework is laid willow brush diagonally with the butts toward the top of the slope and breaking joints throughout, except at the top of the slope. A second layer of brush is laid upon the first in the opposite direction, butts pointing to top of slope and breaking joints, the direction of each layer making a right angle with the other. On top of these layers of brush a second pole framework, fastened in the same manner as the first, is placed and fastened down firmly by the lashings tied to the stakes. As fast as the river and shore work is finished transverse cables made of eight strands of No. 10 wire and 60 ft. long, with an eye in each end, are run across the entire width of the mat every 16 ft., carried to the top of the bank, hauled taut and fastened to trees, stumps or deadmen. They are also fastened to the mat every 16 ft. with wire lashings."

When 400 or 500 ft. of river mattress is made, longitudinal cables* are run out from the mooring barge, one ⅝-in. cable close to the outer edge of the mat, another about 30 ft. inside of the first, the third ½ in. in diameter and 37 ft. from the second, a fourth of the same

* "These cables, which are a continuation of the mattress head cables, are furnished ready made, of the following diameters, ⅝, ½ and ⅜ in., each 1 200 ft. long. They come in coils, and before using are mounted on reels."

dimensions 38 ft. inside of the third, and the fifth and last, $\frac{3}{8}$ in. in diameter and 42 ft. from the fourth, or 45 ft. from the inner edge of the mattress. All are fastened to the mattress every 16 ft., perfectly taut throughout the mat and secured to its head and foot when finished.

The cables are mounted on reels, the outside or $\frac{5}{8}$-in. one being placed in position first.

"The whole cable is reeled off, but the inner end kept on the mooring barge where the reel is set up. After being run down towards and close to the weaving barge, the spare cable is coiled down and tied for further extension. Just above the coil the cable is fastened to the mat with a wire lashing and a specially designed clamp. A tackle is then fastened to the free end and the cable hauled taut by 10 men on the mooring barge. It is then fastened to the mat every 16 ft. with a clamp and lashing. The second $\frac{5}{8}$-in. cable is next run out and fastened, where the second head cable takes hold, then follow the two $\frac{1}{2}$-in. and finally the $\frac{3}{8}$-in. cable. As weaving progresses, the cables are extended until the mat is finished, when the ends are securely fastened around the foot of the mat. After the cables are run, hauled taut, and fastened to head of the mat, all additional hauling is done from lower end of the mat."

If the mattress is to be continuous and very long, when 600 ft. have been woven ballasting can begin; but when made in lengths of from 800 to 1 000 ft., the mat is generally completed before being loaded. The ballasting is accomplished by placing a loaded stone barge outside of the mat, hanging it to the mooring barge by 2-in. manilla rope and holding it close to the mattress by breast lines.

Cottonwood planks 16 ins. wide, 3 ins. thick and 24 ft. long are laid from the barge to the mat, and are continued across the mat in 18-ft. lengths 10 x 2 ins. in section. From two to four of these runs are used and from 10 to 15 men employed on each run. These men wheel out the stone in barrows and dump it along the transverse poles, loading the entire floating mat until only the poles are above water, being careful to load the 50 ft. next the bank heavier than the rest. There is one foreman and one or two master laborers to this gang. The men on each run go out and return together. When the length of the barge is ballasted across the mat, the barge is dropped one length and the planks changed to the new position. The shore work is not ballasted until the river mat is sunk, except where stone is piled on the bank, in which case the shore work, as well as part of the river mat, can be ballasted from the bank.

"As soon as the mattress is completed and ballasted, a loaded stone barge is brought up to the mooring barge; a line is run from its head to the shore capstan of the mooring barge, and another from its lower end to the outer capstan. A man is stationed at each slip line who obeys only the word of the general foreman. Stone is thrown on the head of the mattress, and as soon as the strain on the slip lines is considerable, they are carefully slacked for a short distance. The men at the in-shore capstan begin to haul the head of the stone barge gradually over the submerged mat. The lower end is also gradually hauled up, the object being to bring the stone barge squarely across the mat, stone being continually thrown over on the mat and the barge hauled over until this is accomplished. The line from the down-stream end of the barge is then quickly shifted to another capstan as the barge proceeds in shore."

In the mean time another stone barge is brought up and placed end on the one nearest the shore and securely lashed to it, thus forming a line of barges just below the mooring barges, parallel to them and floating over the head of the mat which is about 10 ft. below the surface, but kept from sinking further by the slip lines.

"In the mean time one coil of 2-in. rope has been placed on the inner end of the first and one on the outer end of the second barge, and the end of each fastened to a timber head. A long 1-in. line also runs from the inner end of the first barge ashore, where a gang of men will be ready to haul the in-shore end of the barge down stream, should the water near the shore be without current. A steam towboat now makes fast with one line to the outer end of the outside barge. A man is at each slip line. A line of men is distributed along each edge of the stone barges. The men on shore have hold of the 1-in. hauling line, the steamboat hanging from and close to the outer edge of the stone barges, and lying with the current. The general foreman is on the mooring barges, watching the slip-line men, and everything is in readiness for the final operation.

"The general foreman now gives the word to throw the stone, and as soon as the slip lines show the required strain, he orders the linesmen on the stone barges to slacken away. He then gives the word, and the slip lines are let go simultaneously. The mat settles quickly at the head, and as the stone barges are dropped down squarely over the body of the mat, the stone being rapidly thrown on to it, it also gradually settles to the bottom. When the required amount of stone is unloaded on the mattress and it is securely on the bottom, the mattress head lines are taken up by a sailor gang, by hauling on the pin lines that are loosely fastened on the mooring barges. These lines pull the pins out of the shackles and set the cables free from the mat. The mooring barges are then allowed to swing to the bank, and all cables are reeled up on their drums, being first washed and oiled."

In the case of a bank which is caving so rapidly that the grading cannot be accomplished before the mattress is built, a foot mattress is constructed joining the main mattress with the bank, the upper bank work being deferred until the main mattress is sunk.

"The abutment and main mattress are constructed as described, except that the hardwood poles along the inner edge are omitted, and only the regular top grillage is laid. After the mattress is sunk, the bank is graded and the shore work laid down to the water edge. A connection or foot mat is then made, to connect the shore work with the submerged river mattress, as follows:

"The weaving barge is brought up alongside and parallel to the bank, with its up-stream end over the head of the mat, and a mattress built like the river mattress, except that it has a lighter head and no mooring barges are used. Instead of the heavy wire cable, wire strand is run from the head up to the top of the bank and fastened there. Five $\frac{5}{8}$-inch cables are used for every 200 ft. of mattress. Two or three cables are also run from the up-stream edge of mat to shore, to prevent current from taking it down stream. The head of the mat when launched off will lap 4 or 5 ft. over the shore work. To launch a shift, the barge is sparred away from the bank. When completed and sunk, the foot mat laps over the river mat, also, 5 ft."

Plate III, Fig. 2, shows the woven mattress under construction on the ways before the top grillage or frame of poles is added; Plate IV, Fig. 1, shows the woven mattresses under construction, partly poled on top, with the bottom frame of the upper-bank revetment in the foreground, and Plate IV, Fig. 2, shows the commencement of the operation of mattress sinking.

Work During 1890–92.—At Ashbrook Neck, during the season of 1890, mattresses were made 300 ft. wide. The bank was cleared 230 x 6 000 ft., or 31.6 acres. The bank was sandy, and was graded by a hydraulic grader, and dressed with shovels to a slope varying from 3 to 1 to 5 to 1, and a height of about the two-third stage. From the shore mat to the top of the grade was paved with rock to a depth of 10 ins.

The distribution of material was as follows: Brush, 0.708 cord per square; poles, 0.136 cord per square; stone, 1.08 cu. yds. per square.

The work consisted of 3 036 lin. ft. of main mat, equal to 8 688 squares; 980 lin. ft. of shore mat, equal to 619 squares; and 2 820 x 65.3 ft. of upper-bank revetment, equal to 1 843 squares.

The cost per square was \$7 69, and per lineal ft., \$30 42.*

* This may include the expense of a small amount of abortive dike work, undertaken at the beginning of the season.

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXV, No. 775.
COPPÉE ON BANK REVETMENT.

FIG. 1.

FIG. 2.

A survey in this year of New Orleans Harbor proper showed but a small change in the bank, except a slight moving out of the 100-ft. contour. There had been no fill between the dikes, but, on the contrary, a noticeable scour. In Carrollton Bend the work had not checked the caving.

The field cost and dimensions of the dikes this year were as follows:

Dimension of section.	Greatest height.	Cost.
415 x 140 ft.	45 ft.	$17 632 05
355 x 130 ft.	50 ft.	13 008 69
400 x 120 ft.	40 ft.	10 901 79

The foundation mattress for these dikes was dissimilar to those previously described. They were made in sections, afterwards joined by wires, and not of the woven type. They were framed mats, the bottom layer of willows being securely nailed to the bottom frame. Three layers of willows were laid, the bottom and top parallel to each other. The mattress was built in four sections—three, 100 x 130 ft., and one, 55 x 130 ft. The different sections were placed in position alongside of a lowering barge and fastened together with No. 10 galvanized wire, making a mattress 355 x 130 ft.

The up-stream frames were built of 3 x 6-in. lumber and strengthened at each toggle pin by three lines of iron rods, one running straight, and one on each side of the pin diagonally, across the mattress, crossing the frames, and fastened with wire to each frame. The frames were placed at right angles to the bank, and top poles were placed longitudinally about 16 ft. apart, to keep ballast from sliding off on steep slopes, and also to give greater strength.

The dimensions of one of the mats were 355 x 130 x 1.75 ft., or 461 squares. The distribution of material and cost was as shown in Appendix A.

There was but little change in crib construction. The cribs placed on the previously mentioned mat were in number and in dimensions as follows: Crib No. 1, 120 x 56 x 6 ft.; No. 2, 152 x 48 x 6 ft.; No. 3, 170 x 40 x 6 ft.; No. 4, 200 x 32 x 6 ft.; No. 5, 274 x 24 x 6 ft.; No. 6, 310 x 16 x 6 ft.

There was 232 512 cu. ft. of material in the cribs, the cost per cubic foot being 3.57 cents. The total cost of the dike was $13 008 69.

Other spurs built at the same time having approximately the same distribution of material cost as follows: Mattress, $9 95 and $9 48 per square; cribwork, 3.58 and 4.31 cents per cubic foot. The average cost of cribwork was 3.59 cents per cubic foot, and of mattress, $9.987 per square. It will be noticed that the cost of mattress per square far exceeds that of the woven mattress in the upper districts, and is much more expensive than the woven mattress made in New Orleans Harbor in 1890.

During the high water of 1891 the Memphis dikes settled 4 ft. at outer ends on an average.

At Fletcher's Bend it was found that the interrupted revetment, heretofore referred to, was not a success. The water attacked the bank in the unprotected intervals, causing it to cave, and it was found necessary to revet them, thus making the work continuous and demonstrating the non-feasibility of interrupted revetment in that portion of the river.

In Ashport Bend in 1891 piles were driven 50 ft. apart along the zero line. Against these the inner edge of the mattress rested, being fastened to them by yokes made of ⅝-in. wire strand running across the mat and connected with it every 16 ft. After sinking the mattress the piles were cut off as close to the ground as possible.

This season, in Hopefield Bend, the cost of hydraulic grading, including clearing and dressing bank was 6¾ cents per cubic yard. The distribution of material in mattress work was: Brush and poles, per square, 0.77 cord; stone, per square, 0.71 ton.

For the connecting mattress: Brush and poles, per square, 1.40 cords; stone, per square, 1.27 tons.

The upper bank was paved at a cost of $6 12 per square. The approximate cost per lineal foot of completed revetment 200 ft. wide below zero line, with bank paved to the two-thirds stage, is given by the engineer in charge of the Hopefield work as follows : Clearing and grading, $1 59; subaqueous mattress, 200 ft. wide, $7 02; connecting mattress, 60 ft. wide, $3 36; paving, $4 59; other expenses, $3 01; total cost, $19 57.

At Ashbrook Neck in 1892 the mattresses were made from 250 to 300 ft. wide, and the bank was graded to a 4 to 1 slope. Brush revetment was carried up 5 ft. above the inside edge of the mattress, and the upper bank was paved with 10 ins. of riprap to the two-thirds stage, or 32.8 ft. on the Arkansas City gauge.

The cost of clearing the bank was $71 50 per acre; grading, $1 21 per lineal foot; dressing grade, 47 cents per lineal foot. The total cost of grading was $1 68 per lineal foot. The cost of mattress per square was $4 69, and the cost of the shore mattress was $5 33. The bank revetted was 4 460 lin. ft., and the cost $30 83 per lineal foot. The average width of the work from top of slope paving to outer edge of mattress was 419 ft.

The upper-bank work took 2.89 cu. yds. of stone per square.

The cost of this work and distribution of materials were as shown in Appendix A.

At Greenville continuous mattresses were sunk 300 ft. wide, and the upper bank graded and paved to the 30-ft. stage.

Cross cables were used extending from the outer edge of the mat some distance up the graded bank, and woven into the mattress; also from eleven to fourteen longitudinal cables, each formed of 19 strands of No. 12 wire, in a mat 300 ft. wide. To hold the mat in place during construction and sinking, ten steel 1-in. wire cables with suitable shackles and 1½-in. pins were used. These cables were in 400-ft. and 800-ft. lengths, with shore ends securely fastened. The mooring barges were held in place by four or six 2-in. manilla lines. The usual slip-lines were used, and at one or two localities Chinese anchors were resorted to.

The mattress cost $4 50 per square, and the material used was: Brush, 0.70 cord per square; poles, 0.13 cord; stone, 0.64 cu. yd.

On the upper bank 3.54 cu. yds. were used per square. The cost of this work and distribution of materials were as shown in Appendix A.

The cost of this entire work during 1892, including administration, plant repairs, etc., was $29.517 per lineal foot.

At Louisiana Bend during the same season the mattresses were made 270 ft. wide. The upper-bank work was very light in places. The material used per square was as shown in Appendix A.

The total extent and cost of the work were:

	Squares.	Per square.
Channel mattress	14 294	$5.045
Pocket mattress	3 722	6.239
Upper revetment brush	2 547	7.059
Paving	2 547	8.329

The total cost of work here during the season was $140 033 78; the amount accomplished, 23 110.5 squares, at $6 06 per square. The cost per lineal foot was $26 49.

The cost of mattress and crib work in New Orleans Harbor in the season of 1891–1892, the work being similar to that of the previous season (frame mattresses in 100 x 120-ft. sections joined together) was: Mattress, $9 28 per square; crib work, 3.7 cents per cubic foot.

Later Work of Commission.—Notwithstanding the fact that the protection work had been increased in strength from the very beginning, the whole history of the work being one of continued increase in dimensions and strength, it was still found unequal to the strain put upon it at certain localities. Surveys and subaqueous measurements and observations made in 1892 and 1893 showed a deepening and deterioration at the outer edge of the river mats at nearly all points. In the report of the Commission for 1893 there is the following statement:

"There has been a deepening from scour along the outer edge of the mats. In some cases the mat has adjusted itself to the new condition, as was intended, while in others the test of its flexibility has been too great and faults have occurred. In some places also there has been settlement in the middle of the mats rather than along their edges, indicating that greater thickness or density is required in very exposed situations. Defects have also been found between the low-water mats and those built on the graded bank.

"The mattresses used in the lower Mississippi for five years past have been the heaviest and widest ever made for like purpose in the history of engineering. To build and sink them in the deepest and swiftest stream upon which such improvement has been attempted is an undertaking of extreme difficulty. It could not have been done successfully in the earlier stages of the improvement."

In view of these facts it was determined to further strengthen the mattress and to make 50 ft. of the outer edge more flexible, so that it would conform to the new scoured slope without being broken; also to give greater stability to the junction of the subaqueous work and the upper-bank revetment. It was claimed that the protection work up to that time had accomplished the purpose for which it was designed, and as it had proved to be the correct method of improvement the necessity for making it permanent arose.

When a reach or bend is not protected, the water at medium high stages and on a rising river exhausts much of its force in cutting down

the bank and deepening the bed. When the bank is protected, the currents pass over the protected portion, unable to expend their energy in work other than the infinitesimally small abrasion of the willows and rock, the water thus gathering increased velocity and greater scouring force. At the outer end of the revetment, where the current generally attains the greatest velocity, this force finds material on which it can act with greater facility, thus deepening the bed immediately at the outer edge of the mattress, undermining it and causing it either to sink and adjust itself to the new condition or break.

It is probable that this will always be the case up to certain limits of depth and rate of flow when, if the mattress work is sufficiently strong, equilibrium will obtain and the work be permanent unless attacked by forces within the bank itself and not produced by the action of the river water. Increased depth and settling at the end of the subaqueous work steepens the slope and increases the tendency of the bank to slough in badly drained localities.

The foot of the mattress should always reach beyond the greatest depth of the inshore thalweg, if possible within specified limits of economical practice.

The revetment built in accordance with the new requirements of flexibility and strength cost as follows, including all expenses except office: *Ashport Bend.*—River mats, per square, \$4 27; connecting mats, \$8 17; pocket mats, per square, \$5 90; paving, per square, \$10 11; grading, per square, $3\frac{1}{4}$ cents. *Daniel's Point.*—River mattresses, per square, \$5 09; connecting mattresses, per square, \$7 81; paving, per cubic yard, \$1 99; grading, per cubic yard, 6 cents.

The work in 1892 in New Orleans harbor consisted of placing mattresses in the spaces between the dikes where caving had occurred or was threatened. These mattresses were practically the same as those constructed and placed under cribs the year previous, and cost \$8 92 per square.

First Fascine Mattress.—At Daniel's Point in this year a new type of mattress construction was attempted, and though the conditions were unfavorable, the plant inadequate, and the labor unaccustomed to the methods, the results demonstrated the great advantage to be attained in substituting the fascine for the woven mattress.

"This new form of mat was constructed of fascines or bundles of brush 12 ins. in diameter and in lengths of 50 and 100 ft., tightly com-

pressed and bound every 3 ft. These fascines were placed at right angles to the bank and formed the woof of the mattress, longitudinal wire strands forming the warp. The top and bottom cables of each pair were clamped together every 3 ft. by long cable clamps. On top of the mattress a grillage of poles was placed and tied down to the frames by galvanized wire."

No further attempt was made in the way of fascine mat construction until 1893, and no estimate is given of the cost of that form of work until that year.

In 1892 the repairs in Hopefield Bend cost as follows: River mattress, per square, \$3 65; connecting mattress, \$5 89; paving, per square, \$11 70; reballasting, per square, \$5 50; grading, per cubic yard, 4½ cents.

At Ashport Bend a mattress was made in the same year in which much more brush was used and the longitudinal cables were doubled, one running above and the other below, reversing every 25 ft., thus forming loops 25 ft. long.

The material used per unit on the Plum Point Reach during the season 1892 is given in Appendix A.

The cost of the Third District work per lineal foot was as follows:

Ashbrook Neck.....	\$29 07	woven mattress and paved bank.
Greenville Harbor..	27 08	
Louisiana Bend....	27 86	

This averages about \$28 per lineal foot. Adding \$6 50 for administration, survey, plant, etc., the total cost is \$34 50.

Fascine Mat Construction.—The last form of woven mattress, though possessing adequate strength, was not sufficiently thick and compact to prevent the water cutting the bank through the interstices or openings between the brush. It also proved too stiff or rigid to be adjusted to the irregularities of the bank, breaking when undermined, instead of taking the new slope, no matter how steep.

The fascine mattress it was expected would be devoid of both of these defects, and though it was feared the cost of construction would far exceed that of the woven type, it was found that after the employees became educated to the new method, the additional expense was slight.

Two forms of these mattresses were constructed, one with the fascines placed normal to the bank, and the other with the fascines

PLATE V.
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COPPÉE ON BANK REVETMENT.

FIG. 1.

FIG. 2.

parallel to it. The former were first used, but the longitudinal fascine mat was supposed to be more flexible in a transverse direction, taking more readily the irregular shape of the subaqueous slope.

The material and plant used in the construction of these mattresses are similar to those adopted for the woven type, with slight modifications shown in Plate V, Fig 1. The following description and drawings of the details of construction of this new form of mattress, taken from the report of the officer in charge of the work on the upper river in 1894, give very clearly the mode of procedure at that time, which has varied but little at all points up to the present season.*

"The plant required consisted of one set of mooring barges, one set of barges with inclined ways, and one set of fascine barges.

"The barges of each set when placed end to end had a length equal to or greater than the width of the mattress to be constructed. The mooring barges were of the same construction heretofore used with the woven type of mattress, and were moored across the current in the same way. The mattress barges were also the same as heretofore used, with the following additions: Underneath the platform was placed a number of cable drums, one under each inclined way or skid, on which was wound and from which was played out, as the construction of the mattress progressed, the steel wire strand which constituted the longitudinal strength of the mattress, and to which the fascines were attached or woven by the method to be hereafter described. The distance between the drums was 8 or 9 ft. according to the particular barge used. At the highest point of each way an iron sheave was placed, over which was passed the strand from the corresponding drum. The drums were all provided with friction brakes by which a uniform tension was kept on the strands while the mat was in process of construction. The fascine barges were ordinary square-end decked barges on which were erected temporary platforms the same level as the platform of the mattress ways. These barges were put end to end and lashed parallel to and close up to the down-stream side of the mat-ways. On the side of the platform nearest the mat-ways were erected the formers in which the brush was laid, compressed and bound into fascines.

Construction of Mattresses.—"The mooring barges being properly moored in position across the current, the mattress ways, to which had been lashed the fascine barges, were brought in position on the down-stream side and secured to the mooring barges by three lines, one at the center and one at each end. The first step was to construct the mat head. This consists of a bundle of poles, 2½ to

* Report of Captain S.W. Roessler, officer in charge of first and second districts, Mississippi River Improvement, Report of Chief of Engineers, 1894, p. 2859.

3 ft. in diameter, well bound together by wire strand, so as to form a beam of great strength, of some rigidity, but having also considerable flexibility. The poles were of hardwood, 5 to 8 ins. in diameter at the butt, and laid so as to break joints with each other. The beam is as long as the mat is wide, and forms the connecting link between the mooring cables and the mattress. It was moored to the bank by steel wire cables, independent of the moorings of the mooring barges. The number of cables used depended on the width of the mat and strength of the current. Eight cables have been used for a mat 300 ft. wide. They are spaced at equal intervals, being closest together near the out-stream end, where the current is strongest, and farthest apart towards the shore, where the current is

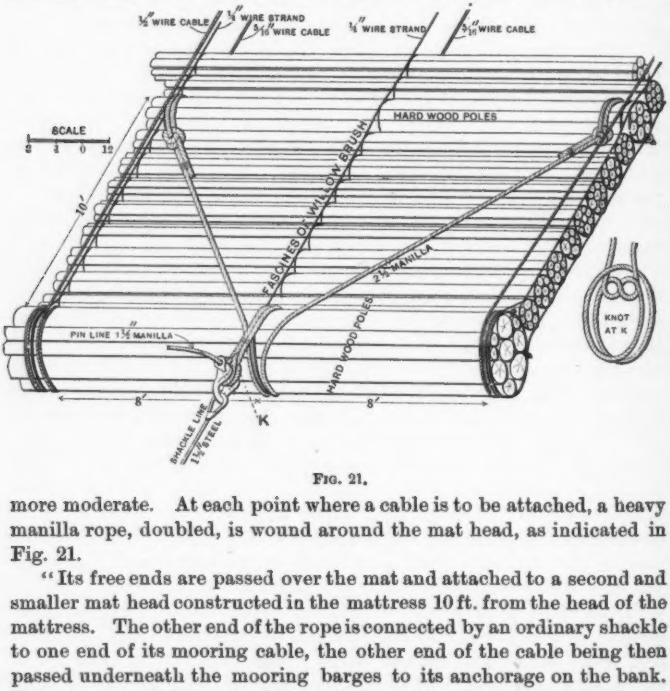

FIG. 21.

more moderate. At each point where a cable is to be attached, a heavy manilla rope, doubled, is wound around the mat head, as indicated in Fig. 21.

"Its free ends are passed over the mat and attached to a second and smaller mat head constructed in the mattress 10 ft. from the head of the mattress. The other end of the rope is connected by an ordinary shackle to one end of its mooring cable, the other end of the cable being then passed underneath the mooring barges to its anchorage on the bank. The wire strands from the drums on the mattress ways are passed over their proper sheaves and wound around and secured to the mat head. The weaving strands, which are ¼-in. steel strand and for convenience cut into lengths of about 50 ft., are also attached to the mat head, one for each of the longitudinal strands upon which the fascines are woven.

"For the construction of the fascines and the mattress the labor is divided into three gangs, one to hand the brush down from the barges, the second to carry the brush to the formers and to construct the fascines, the third to weave the fascines into the mat.

"The second party receiving the brush from the first party carries it to and distributes it in the formers. The brush is put in two layers, one with the tops in one direction and the other with the tops in the opposite direction, care being taken to break joints as far as possible, and especially to prevent two butts from overlapping. Enough brush is put in to make a fascine 10 to 12 ins. in diameter. It is then choked every 8 ft., and bound into a fascine by No. 12 steel wire. The chokers consist of iron chains of suitable length and strength, having one end secured to one side of the former. Each chain is brought over the brush and a lever inserted through a ring in the free end and borne down upon by the weight of one or two men, compressing the fascine while it is being bound with wire. The third party, assisted by the second party, raise the fascine out of the formers, slide it along the skids which connect the former with the top of the mattress ways, and down the latter to its position in the mattress next to the mat head. The weaving strand is then passed over the fascine, down underneath it and up between the fascine and mat head, crossing at the same time the bottom longitudinal strand. It is then put into a 'Haven clamp' and drawn as taut as four to six men can do it with double block and tackle. The strand is temporarily stapled to a pole of the mat head. The second fascine being in place, the weaving strand is passed over the first and second fascine, down underneath the second, and up between the first and second, at the same time crossing the bottom longitudinal strand as before. It is again attached to the clamp and drawn taut as before by block and tackle, and temporarily stapled to a piece of brush in the first fascine. When the strain is first put on the strand, a tap on the pole of the mat head to which it has been temporarily stapled is sufficient to dislodge the staple and allow the strand to completely encircle the first fascine. Details of the method of weaving are shown in Fig. 21. When the ways have been filled the mattress is launched in the usual way and the construction continued. The tenth fascine is made of hardwood brush or poles, and to it are attached the free ends of the large manilla ropes, which are wound around the mat head. The weaving and bottom strands are clamped together by a cable clamp every 10 ft., and at points intermediate between the clamps both strands are stapled to the brush, to prevent the fascines from separating in the process of weaving. On top of the mattress thus constructed are placed rows of poles 16 ft. apart, extending up and down stream. They are lashed to the fascines by No. 7 silicon bronze wire every 5 ft., and at intermediate points by strong steel wire lashings. The object of the rows of poles is two-fold;

first, they prevent the stone from slipping off the mat when it is sunk on a steep slope; and second, by being lashed to the body of the mattress by non-corrosive wire, they prevent the displacement of the brush after the steel wire, weaving strand and other corrosive connections shall have rusted away.

"At the outstream edge of the mat the poles are cribbed up two deep, to better insure against the tipping of the stone when the mat is sunk or when it is subsequently undermined by scour at its edge.

"With a mattress of this type 300 ft. wide, the maximum amount built in a day was 160 ft. with $246\frac{5}{8}$ days' labor. The ballasting and sinking of these mats is performed in a similar manner to that employed in the woven type. In ballasting it is necessary to do the work rapidly and sink the mattress immediately afterward. This precaution is made necessary by the great compactness of the brush fascines and the rapidity with which they accumulate sediment after they have been pressed under water by the ballast. So rapidly do they accumulate sediment that if there is any considerable delay in ballasting, portions of the mattress on which the ballast may be a little excessive may be carried below the surface of the water by the weight of the accumulated deposit before it is ready for sinking.

"Brush not exceeding 3 ins. in diameter at the butt makes a fascine of uniform strength, thickness and compactness.

"One-half and $\frac{5}{16}$-in. strands are used for the bottom longitudinal strands, the $\frac{1}{2}$-in. size being used at the channel edge of the mat, where the current is greatest, and the $\frac{5}{16}$-in. near the shore.

"Smaller strands than these were used in a few of the mats when the supply of the larger strands fell short, but in such cases additional longitudinal strands were stretched over the top of the mat after it was completed and clamped at intervals of 10 ft. to the weaving strand in the same manner as the latter was clamped to the bottom longitudinal cable. The $\frac{1}{4}$-in. strand is used exclusively for weaving. Two forms of clamps have been used, the 'Crosby' and a home-made clamp. Various forms of staples have been used. A staple of the fence-wire type, $1\frac{3}{4} \times \frac{5}{16}$-in., made of No. 9 wire, is a good, cheap and suitable form.

"The oblique position of the mattress head cables to the head of the mattress in the form of construction just described exerts a strong shore thrust on the mat head in the process of sinking. This thrust is taken up by the strong mat head and the mat itself, which together have the requisite rigidity to withstand the thrust without danger of doubling up.

Fascine Mattresses with Fascines Placed Parallel to the Bank.—"Owing to the very much greater lateral flexibility of the mattress in which the fascines are parallel to the bank, it was not deemed safe to have any shore thrusts at all, and the mooring arrangements were accord-

ingly modified. A set of mooring barges was anchored at the head of the mat in the usual way by mooring cables passing obliquely up-stream to deadmen on the shore. A second set of mooring barges was moored in the same way 800 ft. above the lower set. On the deck of the upper barges was placed a continuous line of log deadmen chained to the timber heads, held by the shore cables. These deadmen were to hold the cables mooring the mattress and mattress plant. As the mattress was constructed its mooring cables were attached to it in the manner to be hereafter described, passed underneath the lower mooring barges, carried up stream parallel with the bank and secured to the line of deadmen on the upper barges, thus avoiding any shore thrust upon the mat head. The mattress plant consisted of four mattress ways and their corresponding fascine barges lashed end to end, giving a combined length of 588 ft. The barges were moored parallel to the bank with the ways inclined towards the shore. The fascines were made 588 ft. long, the full length of the mattress. The mattress was constructed by beginning at the water line and extending out stream until the full width of 250 ft. was made. The details of construction were the same as those heretofore described for the mat in which the fascines are normal to the current. To give the mattress more longitudinal strength than the fascines themselves possessed, twelve $\frac{1}{2}$-in. and two $\frac{5}{8}$-in. strands, extending the whole length of the mat were built into it in the following manner: When the construction reached the desired point the longitudinal strand was stretched across the bottom strands of the mattress and clamped to them at the points of intersection by common clamps. The up-stream end of the strand was given two turns around the mattress head and carried back and clamped to itself at 130 ft. For additional security the longitudinal strands were connected together by a diagonal system of backing-up straps 100 ft. below the head of the mattress. The mattress head of this mat differed from previous construction, in that it was a kind of jointed spar, designed to adjust to the bed of the river when sunk. The spar was made of 14 cypress logs about 12 ins. in diameter and varying in length from 28 ft. next to the shore to 14 ft. on the out-stream end, all put in place before launching from mattress boats. The logs were placed on top of the mattress and about 3 ft. from the head of the mattress with laps of 2 ft.

"A $\frac{3}{4}$-in. drift bolt 2 ft. long was driven horizontally through both logs at each lap, and in addition the logs were bound together by several turns of wire strand at the pin points. The logs were secured to the fascines by two wrappings of $\frac{1}{4}$-in. strand, and to every alternate log two of the longitudinal wire strands were made fast.

"Spanning these alternate logs 2-in. manilla ropes were made fast at the same points receiving the longitudinal strands. Each of these rope loops formed an equilateral triangle, with its log for base and with

the shackles of its mattress mooring cables at the vertex. Parallel lines of poles 16 ft. apart were wired to the mattress normal to the current and bank by lashings 5 ft. apart, each alternate lashing being silicon bronze wire. The object of these poles was two-fold; first to give the mattress some stiffness, as without them it was feared the mat would be so flexible as to fold up in sinking; and second, to give to the mattress an element of permanence by its non-corrosive wire lashings. Parallel rows of poles were also placed longitudinally to keep the rock from rolling off."

During the season of 1893 at New Madrid the first large fascine mattress was made. The work consisted of a continuous mattress 250 ft. wide by 900 ft. long, an auxiliary connecting mattress, and a shore paving of 4 ins. of spalls, and 6 ins. of stone extending up the graded bank to the 27-ft. stage. The cost of this work per lineal foot was as follows: River mat fascine, $15 62; connecting mattress fascine, $2 32; paving fascine, $7 58; superintendence and care of plant, $2 26; total, $27 78.

Plate V, Fig. 2, shows a fascine mattress completed. Six mattresses of the fascine type were built and sunk, 658, 825, 913, 1 095, 1 119 and 1 125 ft. long, each being 300 ft. wide. Their cost was $6.282 per square, or $18.846 per lineal foot. Connecting fascine mats were used, costing $11 85 per square. The bank was graded to a 3 to 1 slope after the mattresses were built and sunk, at a cost of 3.8 cents per cubic yard. The shore paving was carried up the bank from the 15-ft. to the 20-ft. stage. In paving, first a layer of spalls 4 ins. thick was laid, and on this rock, 8 ins. at the water edge diminishing to 4 ins. at top. The cost was $10 11 per square, or $5 59 per lineal foot.

The average lineal feet per day's labor in building fascine mats at this point was from 0.386 to 0.495.

Recent Work.—At Hopefield Bend the repairs made in 1890, 1891, 1892 and 1893, constituted practically a renewal of all the original revetment, except two reaches, one 2 000 ft., the other 500 ft. long. These two blocks being destroyed in the flood of 1893, they were renewed by four fascine mattresses 310 ft. wide and 650, 700, 800 and 916 ft. long, costing $6 034 per square, or $18 10 per lineal foot. Connecting mats cost $6.987 per square. The grading cost 5.4 cents per cubic yard. The paving reached from the edge of the connecting mat to 26 to 30 ft. above low water, being carried to this height in order to reach above a sand stratum. The lower 3½ ins. were composed of crushed rock, overlaid

by 6½ ins. of ordinary riprap. The cost was $9 20 per square. The total cost per lineal foot of bank protected was $31 52. For distribution of material see Appendix A.

In building the four mattresses the following averages were made in a day of eight hours.

Mattress.	Length.	Maximum feet made in one day.	Average feet made in one day.	Average number men worked per day.
No. 1	650	140	93	220
No. 2	800	135	127	280
No. 3	700	175	140	300
No. 4	916	173	153	320

At Bolivar Front the upper-bank brush revetment, having rotted in many places, was renewed by a paving of stone 10 ins. thick.

Soundings along this revetted reach showed that the inner portion of the old mattresses had silted up, but at their outer edge they had settled down from 5 to 15 ft. At the lower end of the reach during the season woven mattresses 300 ft. wide were constructed and sunk. They were nearly 2 ft. thick at the inner edge, being reduced to 1 ft. in thickness at outer edge. A much greater amount of brush was used in their construction than had before been used. For the distribution of material in them see Appendix A.

The cost was $25 08 per lineal foot, and $8 36 per square. Similar work at Delta Point cost $26.321 per lineal foot.

In New Orleans Harbor up to 1894 the following work had been done:

A continuous mat 400 ft. long placed in Carrollton Bend; five spur dikes, with intermediate revetment covering three upper intervals and about one-third the lower interval in Carrollton Bend; two spur dikes in Greenville Bend; six spur dikes in Gouldsboro Bend; eight spur dikes in Third District Reach.

In the Third District and Carrollton Bends caving took place in the intervals between the dikes. The officer in charge states:

"Spur dikes without intermediate revetment have been successful in some straight reaches, and on concave banks of large radii, but in the abrupt bends the dikes alone are only locally effective."

In the season 1893-94, woven mattresses were still being constructed and sunk in the Third District, at Ashbrook Neck, Greenville Harbor and Lake Providence. At the latter locality fascine work was also

undertaken and very satisfactory results obtained. The mattresses at the other three points specified were reinforced by an extra amount of brush, at Ashbrook Neck the inner 100 ft. only having an additional layer of brush added, while at Greenville Harbor and Lake Providence Reach the extra layer was added all over the mat. The engineer in charge justly condemned the practice of obtaining additional thickness in woven mattresses by the extra layer of brush, on account of the increased stiffness attained. This was the general verdict at all other points, and the necessity for a remedy for this fault produced the fascine type. The fascine mats used at Lake Providence during this season were similar to those of the upper districts, being sunk with fascines normal to the bank.

At Lake Providence the stone on the subaqueous work was increased to 1¼ cu. yds. per square, enough to cover the mattress 4 ins. deep, and the same amount deducted from the upper-bank paving, it being deemed better practice than the old method of 10 ins. of paving and a light mat covering. The engineer recommended spalls on the upper bank in preference to larger riprap, as it packs closer, leaving fewer spaces for the water to penetrate.

The following is a statement giving the cost per unit of labor and comparative average cost per lineal foot of revetment work at Ashbrook Neck, Greenville Harbor and Lake Providence during the season 1994–95.

COST PER UNIT OF LABOR.

Kind of work.	Ashbrook Neck.	Greenville.	Lake Providence.
Mat work, woven, per square..........	$1.249	$1.290	$1.824
Mat work, fascine, per square.........	......	......	2.171
Grading, hydraulic, per 100 lin. ft.....	1.736	2.308	1.228
Grading, hand, per 100 lin. ft..........	......	3.921	0.629
Paving slope, per square	1.682	1.102	0.863

For the distribution of material on these works see Appendix A.

COMPARATIVE COST AND PERCENTAGE OF LABOR AND MATERIAL.

Items.	Ashbrook Neck. Per cent.	Greenville. Per cent.	Lake Providence. Per cent.
Labor..................................	45.3	36.3	46.6
Material................................	54.7	63.7	53.4
Cost per lineal foot....................	$30 25	$28 22	$30 41

The average cost of all this work during the season was $29 33, that during the season of 1892–93 being $28, an increase of $1 33 in 1894. About 50% more brush and 15% more stone were used, which would more than account for the increased price.

Conclusion.—Since the season of 1894 there has been little change in the general form of bank revetment.

The vertical space is left at the top of the bank. The rest of the upper slope is paved, and the subaqueous work is of the fascine type, both continuous and auxiliary. The cost of protection per lineal foot has been approximately $30 at most troublesome localities.

Improvements, both of a mechanical and economical nature, have been attained. The fascine formers have been placed on the mattress barge, thus dispensing with intermediate barges, and mechanical devices have been designed to save labor and perform the work with greater facility and better results.

It will be noticed that in the transverse fascine mat, by dispensing with the ties which form the fascines, that is, by placing the willows in the fascine mattress, when made of the strongest form, with top as well as bottom continuous longitudinal cables, there will result a mattress somewhat similar to the old type of wire net construction used in 1880, but of much greater dimensions and infinitely stronger.

The later mattresses used in New Orleans resemble very much the old wooden pin form used at Delta Point and Memphis prior to 1880, though they are also much stronger.

The early types were more compact than the woven mattress which was adopted in 1882 and used up to 1895, and though the latter was increased in size and given a strength adequate to resist all strains, it was impossible to weave it sufficiently close and compact to prevent the erosive action of the water on the bank through the openings between the willows.

All the recent surveys of the revetted reaches tend to prove that where the bank is protected, no matter how strong the revetment, the channel is deepened just outside of the subaqueous work, and under its outside edge, causing it to take a steep grade. If the mattress is built with sufficient flexibility, strength and compactness, the ultimate result will be the steepening of the subaqueous slope without destroying the efficiency of the work.

When submerged spur dikes are placed in the caving bends, their

efficiency is dependent, to a great extent, on the radius of the bend, the distance between them, and the material of which the bank is composed.

Where the bend is very abrupt and the bank sandy, dikes are of little value. Where the bend is abrupt and the material clay and buckshot, they should be placed not farther apart than 500 ft., and even then it may be necessary to protect the intervals between them.

A thorough knowledge of the river in the vicinity of a reach to be protected is of great importance. Much money can be wasted by not studying the movement of its currents and bars in the locality, in order to select the best point for beginning the work. If placed too high under the bar, dead water may soon prove it a waste of material and an unnecessary expense, while at localities where the bar is receding the failure to place the upper end of the work at the correct place may prove disastrous. A careful survey of the river in the vicinity is very essential.

In the hydraulic grading and in paving the upper bank, the greatest trouble lies in the difficulty with which uniform slopes are obtained in certain materials and with strata in certain relative positions. It is often necessary to do considerable dressing and regrading with sluice boxes, shovels or teams, where the sand strata become washed in pockets some distance below the required grade.

Appendix B gives the distribution of material in the work, and the cost from 1878 to 1894.

The conditions under which the revetment was constructed, the variation in price of material and labor, the difference in form of construction and the irregular manner in which the records have been kept make any comparison of the different forms of doubtful value.

As the education of the labor to the methods has become more nearly perfect, the cost of the labor item per unit of product has decreased; but the great increase in strength, extra use of iron, etc., has partly compensated for that decrease. Since 1878 the cost of rock, brush and poles has decreased, also that of other articles used. The rate of laborer's pay per hour has remained practically the same from 1882 to the present time. The cost of subsistence has not varied to a great extent, notwithstanding the difference in cost of food supplies at different times.

The bank revetment work which the author has endeavored to de-

scribe is probably more extensive than any like engineering construction in the world. A mattress 300 ft. wide by 1 200 ft. long represents a superficial area of about 8 acres, and when one realizes that this vast willow carpet, over a foot thick, is placed on the bottom of the river in depths of from 40 to 100 ft., and against currents of from 5 to 8 ft. per second, the difficulty of the enterprise will be appreciated.

Though much of the revetment from Cairo to New Orleans has needed repairs from year to year, and in some reaches has required renewal as a whole, it may be said to have been eminently successful in the protection of harbor fronts and the prevention of cut-offs and outlets, and fairly so in the control of bank caving, and the resulting change in position and flow of the river.

At some points, where the material of the bank was friable and the currents very strong, the earlier forms of revetment proved too light and were entirely swept away, the shore line continuing to move back. Also considerable reaches of protection work needing repairs and re-inforcement at the ends have been destroyed because of the lack of funds, due to the failure of appropriations, etc. In the later work the results have been beneficial and satisfactory, and the loss but slight.

APPENDIX A.

The following tables give the distribution of material used and the cost of revetment per unit, from 1878 to 1894. A square is equal to 100 sq. ft. Except where hardwood is designated, willow was used for brush, and willow or cottonwood for poles. Except where spalls are specified, the rock was in pieces varying from 10 to 100 lbs. in weight.

MEMPHIS HARBOR, 1878 TO 1880, MATS AND REVETMENT; 2 385 SQUARES OR 1 300 LIN. FT.

Materials.	Total amount.	Per square.	Per lineal foot.
Willow brush, cords	2 760	1.16	2.12
Cottonwood poles, number	7 520	3.15	5.80
White oak pins, 4 ft. x 1 in.	800	.33	.62
" 12 x $\frac{3}{4}$ ins	6 300	2.64	4.85
No. 12 wire, pounds	1 950	.82	1.50
Stone, cubic yards	1 154	.48	.88
Sandbags, number	1 500	.63	1.15
Cypress piles, 40 ft. x $1\frac{1}{2}$ ins.	50	one every 26 ft.	

MEMPHIS, 1881.

This work embraced 900 squares of mattress and 131 squares of upper-bank revetment. The distribution of materials was as follows: Willow brush, 1 546 cords, 1.5 cords per square; cottonwood poles, 10 cords, 0.01 cord per square; wire, 2 430 lbs., 2.3 lbs. per square; gravel, 570 cu. yds., 0.55 cu. yd. per square; stone, 187 cu. yds., 0.18 cu. yd. per square; sacks, 1 750, 1.7 per square.

WOVEN MATTRESS WORK, DELTA POINT, 1882 AND 1883.

Items.	Amount. Per square.	Amount. Per lineal foot.	Cost. Per square.	Cost. Per lineal foot.
Brush, cords	.41	.6	$1 03	$1 52
Poles, number	1.2	1.66	38	53
No. 12 wire, pounds	1.2	1.70	06	08
Spikes, 6-in., pounds	.34	.5	02	03
Nails, pounds	.21	.3	01	01
Rock, cubic yards	.42	.6	80	1 14
Labor	....	....	60	86

One man built 28 squares, or 2 lin. ft. per day. The cost of the mattress was $2 90 per square, or $4 17 per lineal foot.

UPPER-BANK REVETMENT WORK, DELTA POINT, 1881 TO 1883.

Items.	Amount. Per square.	Amount. Per lineal foot.	Cost. Per square.	Cost. Per lineal foot.
Brush, cords	.4	.3	$1 01	$0 76
Poles, number	2.0	1 5	64	48
No. 12 wire, pounds	5.0	3.75	25	19
Spikes, 6-in., pounds	.8	.6	04	03
Rock, cubic yards	2.0	1.5	3 80	2 85
Labor	...	....	1 15	86

One man built $1\frac{1}{2}$ squares or 2 lin. ft. per day. The cost per square was $6 89, and the cost per lineal foot was $5 17. The mat and upper-bank revetment cost about $4 05 per square or $9 34 per lineal foot.

MATS AND REVETMENT, MEMPHIS, 1882 AND 1883; 2 005 SQUARES.

Materials per square: Willow brush, 1.4 cords; cottonwood poles, 2.5 cords; oak pins, 4 ft. by 1 in., 0.35; oak pins, 1 ft. by ¾ in., 1; wire, 1.4 lbs.; stone, 0.54 cu. yds.; sand, 0.1 bag.

HOPEFIELD BEND, 1882 AND 1883.

The following statement gives the distribution of material in 1 127 lin. ft. of mattress 140 ft. wide, 194 x 25 ft. of foot mat, and 194 x 16 ft. of upper-bank revetment; 1 657 squares in all. Willow brush, 840 cords, 0.5 cord per square; poles, 105 cords, 0.1 cord per square; wire, 2 534 lbs., 1.5 lbs. per square; rope, 80 lbs., 0.05 lbs. per square; spikes, wrought, 1 950 lbs., 1.2 lbs. per square; nails, 200 lb., 0.12 lb. per square; stone, 585 cu. yds., 0.35 cu. yd. per square; gunny bags, each containing 120 lbs. of clay, 4 300, 2.6 per square.

LAKE PROVIDENCE, 1882 AND 1883; MATS AND BRUSH REVETMENT, 250 SQUARES OR 100 LIN. FT.

	Amount.		Cost.	
Items.	Per square.	Per lineal foot.	Per square.	Per lineal foot.
Brush, cords	.61	1.54	$1 07	$2 69
Stone, cubic yards	.41	1.02	82	2 04
Poles, cords	.05	.12	10	25
Spikes, pounds	.51	1.27	02	06
Wire, pounds	.89	2.23	06	16
Iron rods, pounds	4.00	10.00	20	50
Towing	....	......	33	83
Labor	....	......	1 87	4 67
Total cost			$4 47	$11 20

The mats were 250 ft. wide; the foot mats, 40 ft.; the revetment, 60 ft.

PLUM POINT REACH, 1884.

Mat, 175 x 2 010 ft.; 3 517 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 741.41	0.49	0.86
Poles, cords	198.70	0.05	0.09
Wire, pounds	9 175	2.61	4.56

Mat, 175 x 1 750 ft.; 3 062 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 417.75	0.46	0.81
Poles, cords	149.5	0.05	0.08
Wire, pounds	8 650.0	2.82	4.94
Stone, cubic yards	1 757.5	0.57	1.00

Mat, 175 x 1 713 ft.; 2 998 squares.

Materials.	Total amount.	Per square.	Per lineal foot.
Brush, cords	1 982	0.66	1.15
Poles, cords	210	0.07	0.12
Wire, pounds	11 100	3.70	6.48
Stone, cubic yards	1 696	0.57	0.99

Memphis Harbor, 1884 and 1885.

The following amounts are for upper-bank and subaqueous work combined, a total of 12 937 squares. The mats were 150 to 250 ft. wide and 1 500 ft. long. Brush, 11 978 cords, 0.93 cord per square; poles, 440 cords, 0.03 cord per square; stone, 13 654 cu. yds., 1.06 cu. yds. per square; wire, 95 142 lbs., 7.36 lbs. per square; wire rope, 14 733 lbs., 1.14 lbs. per square; iron rods, 85 867 lbs., 6.64 lbs. per square; spikes, 22 500 lbs., 1.74 lbs. per square.

Hopefield Bend, 1884 and 1885.

The following materials were used in constructing 11 003 squares of upper-bank and subaqueous work combined, the mattresses being 150 ft. wide and 2 978 ft. long: Brush, 14 674 cords, 1.33 cords per square; poles, 282 cords, 0.02 cord per square; stone, 6 487 cu. yds., 0.59 cu. yd. per square; wire, 98 090 lbs., 8.91 lbs. per square; spikes, 17 800 lbs., 1.62 lbs. per square; gravel, 3 135 cu. yds., 0.29 cu. yd. per square.

Hopefield Bend, 1885 and 1886; 2 813 Squares, Continuous and Connecting Mattress.

Items.	Amount.	Cost.	Material per square.	Cost per square.
Pay-roll	....	$2 539 92	....	$0 90
Subsistence	....	949 28	....	34
Brush, cords	1 818	2 255 95	.64	80
Poles, cords	171½	291 17	.06	10
Stone, cubic yards	1 620	1 620 00	.58	57
Iron, pounds	8 640	393 76	3.07	14
Wire, pounds	24 310	924 51	8.64	33
Wire rope, feet	4 825	205 06	1.72	08
Spikes and nails, pounds	5 150	165 20	1.83	06
Tug hire	....	35 00	....	01
		$9 379 85		$3 33

The woven mats were 150 ft. wide. The cost of bank covering was $3 85 per square.

Hopefield Bend, 1885 and 1886; 800 Squares Upper-Bank Revetment and Grading.

Items.	Amount.	Cost.	Material per square.	Cost per square.
Pay-roll	....	$1 994 28	....	$2 49
Subsistence	....	639 00	....	80
Brush, cords	1 114	1 371 55	1.39	1 71
Poles, cords	80	135 83	.10	17
Stone, cubic yards	882	882 00	1.10	1 10
Iron, pounds	1 822	57 43	2.28	07
Wire, pounds	11 260	435 42	14.07	55
Spikes and nails, pounds	2 350	64 80	2.94	08
Coal, bushels	892½	89 25	1.11	00
Miscellaneous	....	1 75	....	11
		$5 671 31		$7 08

This does not include the cost of general repairs, administration, etc. The area was 1 140 ft. long and 70 ft. wide.

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

Subaqueous or Foundation Mattress, 3 524 squares.

Items.	Amount.	Cost.	Amount per square.	Cost. per square.
Labor	......	$4 196 27	....	$1 19
Subsistence	......	....	....	....
Brush, cords	2 208.6	2 164 43	.63	62
Poles, cords	465.5	632 17	.13	18
Stone, cubic yards	1 997.7	2 188 44	.57	62
Spikes, pounds	4 000	104 00	1.13	03
Iron, pounds	1 035	18 98	.30	01
Lumber, feet	6 884	94 28	1.95	02
Manilla rope, pounds	4 154	465 32	1.18	13
Miscellaneous	......	110 78	....	03
Wire, pounds	18 500	740 00	5.22	21
Wire cable, pounds	10 500	459 37	2.98	13
		$11 174 04		$3 17

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

1 112 Squares of Upper Bank Revetment.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$2 239 58	....	$2 02
Subsistence	....	....	....	....
Brush, cords	1 550	1 667 68	1.39	50
Poles, cords	145	189 70	.13	17
Stone, cubic yards	1 190	1 304 76	1.07	1 16
Spikes, pounds	2 700	81 00	2.43	07
Wire, pounds	6 704	268 16	6.03	25
		$5 750 88		$5 17

These amounts do not include grading for the shore cribs.

MEMPHIS DIKE CONSTRUCTION, 1886 AND 1887.

1 003 898 Cu. Ft. of Cribwork.

Items.	Amount.	Cost.	Amount per cubic foot.	Cost per cubic foot.
Labor	....	$10 159 56	....	$0.01
Brush, cords	4 003	3 933 20	0.004	.004
Poles, cords	987	1 292 11	.0009	.001
Stone, cubic yards	4 494	4 929 54	.005	.005
Spikes, pounds	13 553	383 89	.01	.0004
Miscellaneous	....	155 74	....	.0002
Wire, pounds	42 824	1 712 96	.04	.002
Wire cable, pounds	25 675	1 123 28	.02	.001
Iron, pounds	7 260	153 11	.007	.0001
		$23 843 39		$0.024

MEMPHIS, 1886 AND 1887, SUBAQUEOUS MATTRESS; 7 856 SQUARES OR 2 950 LIN. FT.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 358 03	....	$1 06
Subsistence	...	400 33	....	05
Brush, cords	5 054	5 620 04	0.64	72
Poles, cords	765	1 197 50	.09	15
Stone, cubic yards	4 195	7 073 61	.53	90
Wire, pounds	38 498	1 539 92	4.90	20
Wire cable, pounds	15 693	697 98	2.00	08
Spikes and nails, pounds	7 700	207 45	.98	03
Iron, pounds	5 477	148 01	.70	02
Lumber, feet	9 044	150 78	1.15	02
Manilla rope, pounds	2 360	264 50	.30	03
Coal, boxes	200	75 00	.02	01
Miscellaneous	....	113 60	....	02
		$25 846 75		$3 29

The cost per lineal foot of this continuous mattress was $8 76. Including repairs to plant, all office and administration expenses, etc., it was $4 52 per square and $11 97 per lineal foot.

HOPEFIELD BEND, 1887 AND 1888, SUBAQUEOUS MATTRESS; 7 546 SQUARES.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$5 491 95	....	$0 73
Subsistence	....	2 241 80	....	30
Brush, cords	3 752	4 314 80	0.50	57
Poles, cords	833	1 457 75	.11	19
Stone, cubic yards	3 821	5 784 96	.50	76
Wire, pounds	39 708	1 588 32	5.25	21
Wire strand, pounds	11 530	547 67	.153	07
Spikes and nails, pounds	6 900	205 45	.91	03
Lumber, feet	3 100	62 00	.41	01
Iron, pounds	1 130	29 75	.15	003
Manilla rope, pounds	1 200	135 00	.16	01
Miscellaneous	....	24 28	....	003
		$21 883 73		$2 89

HOPEFIELD BEND, 1887 AND 1888, UPPER-BANK REVETMENT, INCLUDING GRADING; 6 182 SQUARES.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 092 72	....	$1 31
Subsistence	....	2 907 74	....	47
Brush, cords	5 470	6 521 94	.88	1 05
Poles, cords	603	1 031 65	.10	17
Stone, cubic yards	4 032	6 103 42	.65	99
Wire, pounds	34 678	1 387 12	5.61	22
Wire strand, pounds	1 450	68 88	.24	01
Spikes and nails, pounds	2 400	73 20	.39	01
Coal, boxes	2 103	787 20	.34	13
Iron, pounds	915	22 77	.15	003
Miscellaneous	....	125 79	....	02
		$27 122 43		$4 38

HOPEFIELD BEND, 1888 AND 1889, SUBAQUEOUS MATTRESS, 196 FT. WIDE; 9 394 SQUARES.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 191 35	....	$0 87
Subsistence	....	2 958 86	....	32
Brush, cords	4 977	6 125 60	0.53	65
Poles, cords	678	1 185 50	.07	13
Stone, tons	4 442	6 973 94	.47	74
Wire, pounds	48 814	1 911 83	5.20	20
Wire strand, pounds	12 620	534 98	1.34	06
Spikes, pounds	3 300	90 81	.35	01
Lumber, feet	6 325	104 61	.67	01
Iron, pounds	1 623	40 57	.17	004
Manilla rope, pounds	1 650	184 80	.18	02
Miscellaneous	....	43 22	....	005
		$28 346 07		$3 02

HOPEFIELD BEND, 1888 AND 1889, UPPER-BANK REVETMENT, ABOUT 142 FT. WIDE; 6 635 SQUARES COVERED.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	....	$8 572 37	....	$1 30
Subsistence	....	3 095 92	....	47
Brush, cords	6 233	7 885 20	0.94	1 19
Poles, cords	621	1 131 75	.09	17
Stone, tons	5 089	7 989 73	.77	1 20
Wire, pounds	53 095	1 821 38	8.00	27
Wire strand, pounds	336	13 43	.05	002
Spikes, pounds	2 000	58 04	.30	01
Manilla rope, pounds	400	44 80	.06	007
Miscellananeous	....	21 34	....	003
		$30 633 96		$4 62

The above does not include grading.

BOLIVAR, 1888 AND 1889.

This work comprised 10 300 squares of mattress, 180 to 250 ft. wide, and 2 842 squares of upper-bank revetment. The amount of materials was as follows: Brush, 9 639 cords, 0.73 cord per square; poles, 1 659 cords, 0.12 cord per square; stone, 10 154 cu. yds., 0.77 cu. yd. per square; wire, 129 310 lbs., 984 lbs. per square; wire cable, 25 025 lbs., 1.9 lbs. per square; spikes, 33 100 lbs., 2.52 lbs. per square; iron rods, 51 924 lbs., 3.95 lbs. per square; clevises, lap rings, 8 500 lbs., 0.65 lb. per square; lumber, 7 081 ft., 0.54 ft. per square; staples, 1 858 lbs., 0.01 lb. per square.

HICKMAN HARBOR, 1889 AND 1890, 2 736 SQUARES OF SUBAQUEOUS MATTRESS, 300 FT. WIDE.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	.....	$3 637 99	....	$1 33
Subsistence	.....	104 78	....	04
Brush, cords	1 812	1 902 60	.66	70
Poles, cords	250	312 50	.09	12
Stone, cubic yards	1 717	2 508 14	.62	91
Wire, pounds	22 560	621 83	8.22	22
Wire strand, pounds	4 061	1 45 79	1.48	05
Spikes and nails, pounds	1 000	27 50	.36	01
Lumber, feet	6 985	75 10	2.56	03
Iron, pounds	1 480	20 60	.54	01
Manilla rope, pounds	700	72 55	.25	02
Piling, feet	455	36 40	.17	02
		$9 465 78		$3 46

HICKMAN HARBOR, 1889 AND 1890, 1 378 SQUARES OF UPPER-BANK REVETMENT 143 FT. WIDE, GRADING INCLUDED.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Labor	.....	$4 571 41	....	$3 31
Subsistence	.....	305 00	....	22
Brush, cords	1 317	1 382 85	0.95	1 00
Poles, cords	131	163 50	.09	1185
Stone, cubic yards	1 508	2 202 90	1.095	1 60
Wire, pounds	5 524	155 10	4.01	1135
Spikes and nails, pounds	300	8 25	.22	006
Lumber, feet	1 000	15 00	.725	011
Coal, bushels	2 292	229 20	1.662	166
Oil, etc	.....	76 58	....	055
		$9 109 79		$6.000

The total revetment on this work, above and below water cost, including charges on plant, etc., $6 00 per square and $24 77 per lineal foot.

LOUISIANA BEND, 1889.

This work comprised 21 695 squares of subaqueous mattress and 5 672 squares of paving, 10 ins. thick. The materials used were as follows: Stone, 48 161 cu. yds., 1.76 cu. yds. per square; brush, 18 813 cords, 0.68 cord per square; poles, 3 362 cords, 0.12 cord per square; wire, 167 440 lbs., 6.16 lbs. per square; wire cable, 329 560 lbs., 12.02 lbs. per square; spikes, 36 961 lbs., 1.35 lbs. per square.

GREENVILLE, 1889; DIKE No. 2.

Foundation Mattress, 290 x 290 Ft. or 841 Squares.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per square.	Cost per square.
Brush, cords	553	$1 27¼	$705 07	0.657	$0 84
Poles, cords	141	1 47½	207 97	.168	25
Stone, tons	767	1 95	1 496 65	.912	1 78
Wire, coils	34	3 37	114 58	.040	14
Cable, coils	6	42 27	253 62	.007	30
Spikes, 6-in., kegs	4	3 25	13 00	...	..
Spikes, 9-in., kegs	5½	3 12½	15 63	.011	03
Staples, kegs	1¼	5 00	6 25	.001	01
Total materials			$2 811 77		$3 35
Labor, hours, including subsistence	5 630	16	$900 80	6.69	$1 07
Sailor work, hours, including subsistence	737	16	117 92	0.88	14
Total labor			$1 018 72		$1 21
Grand total			$3 830 49		$4 56

Crib No. 1, 212 32 x 8 Ft.; 54 272 Cu. Ft.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	228	$1 27½	$290 70	0.420	$0 54
Poles, cords	100	1 48	148 00	.184	27
Stone, tons	324	1 50	486 00	.597	90
Wire, coils	32	3 37	107 84	.059	20
Cable, coils	2½	42 27	105 67	.005	20
Spikes, 6-in., kegs	2¾	3 25	8 94	....	..
Spikes, 9-in., kegs	7¾	3 12½	24 22	.013	05
Total material cost.			$1 171 37		$2 16
Labor, hours, including subsistence	2 686	16	$429 76	4.95	$0 79
Sailor work, hours, including subsistence.	610	16	97 60	1.12	18
Total			$527 36		$0 97
Grand total			$1 698 73		$3 13

Crib No. 2, 170 x 16 x 8 Ft.; 21 760 Cu. Ft.

Materials.	Amount.	Cost per unit.	Cost, total.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	95	$1 27½	$121 12	.437	$0 55
Poles, cords	52	1 48	76 96	.239	35
Stone, tons	119	1 95	232 05	.547	1 08
Wire, coils	27	3 37	90 99	.124	42
Cable, coils	1½	42 27	63 40	.007	29
Spikes, 6-in., kegs	1¾	3 25	5 69	....	..
Spikes, 9-in., kegs	2¼	3 12½	7 03	....	..
Spikes, 9-in., kegs	1½	5 70	8 55	.002	09
Total			$605 79		$2 78
Labor, including subsistence, hours	1 351	16	$216 16	6.21	$0 99
Sailor work, including subsistence, hours	310	16	49 60	1.42	23
Total			$265 76		$1 22
Grand total			$871 55		$4 00

Revetment, 230 Squares.

Materials.	Amount.	Cost per unit.	Total cost.	Amount per square.	Cost per square.
Brush, cords	325	$1 09	$354 25	1.413	$1 54
Poles, cords	45	1 48	66 60	.196	29
Stone, tons	649	1 95	1 265 55	2.822	5 50
Wire, coils	22	3 37	74 14	.096	32
Spikes, 6-in., kegs	½	3 25	1 62	....	..
Spikes, 9-in., kegs	3	3 12½	9 37	....	..
Spikes, 9-in., kegs	½	5 70	2 85	.017	06
Total material			$1 774 38		$7 71
Grading, labor and subsistence, hours	5 000	16	$800 00	21.74	$3 48
Construction, labor and subsistence, hours	3 584	16	593 44	15.58	2 58
Total			$1 393 44		$6 08
Grand total			$3 167 82		$13 77

Land Crib, 3 000 cu. ft.

	Amount.	Cost per unit.	Total cost.	Amount per 100 cubic feet.	Cost per 100 cubic feet.
Brush, cords	7	$1 09	$7 63	0.233	$0 25
Poles, cords	10	1 48	14 80	.333	49
Stone, cords	16	1 95	31 20	.533	1 04
Wire, coils	2	3 37	6 74	.066	22
Total materials			$60 37		$2 00
Labor, including subsistence, hours		16	32 32	6.073	1 08
Grand total			$92 69		$3 08

New Orleans Harbor, 1890 and 1891.

Foundation Mat, 355 x 130 x 1.75 Ft., or 461 Squares.

Items.	Amount.	Cost.	Amount per square.	Cost per square.
Brush, cords	608	$1 258 35	1.32	$2 73
Lumber, feet	16 222	176 80	3.51	38
Rock, tons	299	597 34	.65	1 30
Wire, pounds	991	39 64	2.15	08
Nails, pounds	4 200	132 90	9.12	29
Chain, pounds	3 787	132 54	8.240	28
Bolts, number	86	4 30	·18	01
Fish plates, number	131	9 17	.28	02
Subsistence		360 00	....	78
Labor		1 995 91	....	4 33
Total		$4 706 95		$10 20

Cribs, 2 325 Cu. Ft.

Brush, 1 387 cords, costing $2 870 67; poles, 68 cords, costing [$140 76; rock, 580 tons, costing $1 160 09; lumber, 37 380 ft., costing $407 44; No. 10 wire, 2 090 lbs., costing $83 60; iron rods, 456 lbs., costing $15 96; nails, 2 150 lbs., costing $74 25; subsistence, $450; labor, $3 100 16. Total cost, $8 303 74; cost per cubic foot, 3.57 cents.

Ashbrook Neck, 1891 and 1892, Mattresses 300 Ft. Wide and Upper-Bank Paving.

This work required the following materials: Brush and poles, 2.565 cords per lineal foot; stone, 5.136 cu. yds.; wire cables, 14.8 lbs.; wire, 19.517 lbs.; spikes, 2.6 lbs. The distribution per square was as follows: Brush, 0.661 cord; poles, 0.132 cord; stone, 0.688 cu. yd. The cost per unit is given in the tabular statement immediately following.

	Labor and subsistence.	Material.	Total.
Mat work, per square	$1.573	$3.117	$4.690
Foot mat, per square	1.719	3.616	5.333
Revetment, per square	2.388	6.809	9.197
Paving, per square	1.617	7.006	8.623
Clearing bank, per acre	71.500	.....	71.50
Loading stone, per cubic yard	0.589	. ...	0.589
Grading, per lineal foot	0.840	0.369	1.210
Dressing, per lineal foot	0.457	.....	0.457

GREENVILLE, 1891 AND 1892; 300-FT. WOVEN MAT AND PAVING.

Kind of work.	Cost per unit. Labor and subsistence.	Material.	Total.
Mattress, per square	$1.332	$3.167	$4.499
Revetment, per square	2.042	7.502	9.544
Paving, per square	1.121	7.474	8.594
Grading, per lineal foot	.5387	.213	.7523
Dressing, per lineal foot	.0755	.00	.6755
Loading stone, per cubic yard	.4520	.003	.4550

LOUISIANA BEND, 1891 AND 1892, 270-FT. MATS AND 10-IN. PAVING.

Materials.	Mattress.	Connecting mat.	Upper-bank revetment.	Paving.
Brush, cords	0.8	0.8	1.2	
Poles, cords	.12	.12	.12	
Stone, cubic yards	.7	1.25	1.25	3.00
Wire, pounds	5.2	5.2	5.2	
Cable, pounds	4.4	4.4	4.4	
Spikes, pounds	0.16	0.16		

PLUM POINT REACH, 1892 AND 1893.

River Mattress, Heaviest Woven Type.—Brush, 0.948 cord per square; poles, 0.111 cord; stone, 0.647 cu. yd.; wire, 8.07 lbs.; wire strand, 2.9 lbs.; spikes, 0.4 lb.; cable clamps, 0.114; staples, 0.048 lb.; piles, 0.0092.

Paving.—Stone, 0.385 cu. yd. per square, and 1.709 cu. yds. per lineal foot; spalls, 0.113 and 0.501 cu. yd.

Connecting Mats.—Brush, 1.117 cords per square; poles, 0.136 cord; stone, 2.228 cu. yds.; wire, 6.716 lbs.; wire strand, 2.024 lbs.; spikes, 0.24 lb.; cable clamps, 0.0078; staples, 0.0012 lb.

Pocket Mats.—Brush, 0.83 cord per square; poles, 0.145 cord; stone, 1.55 cu. yds.; wire, 7.44 lbs.; wire strand, 2 lbs.; clamps, 0.065; staples, 0.025 lb.; spikes, 0.206 lb.

Cost of Work.—River mats, $4.27 per square; connecting mats, $8.17 per square; pocket mats, $5.90 per square; paving, $10.11 per square; grading, 3¾ cents per cubic yard; clearing, $42.56 per acre. Cost per lineal foot of revetment complete, $19.22.

ASHBROOK NECK, 1892 AND 1893.

The mattress in this work was 250 ft. wide, and the slope of the paved bank was 4 to 1. The distribution of the materials was as follows: Brush, 0.62 cord per square, 2.025 cords per lineal foot; poles, 0.14 cord per square, and 0.41 cord per lineal foot; stone, 6.137 cu. yds. per lineal foot; wire, 7.7 lbs. per square, and 22.95 lbs. per lineal foot; wire cable, 4 and 13.6 lbs. This work cost $29 07 per lineal foot.

GREENVILLE, 1892 AND 1893.

This work included woven mattresses and a paved upper bank on a slope of 4 to 1. The distribution of materials was as follows: Brush, 0.71 cord per square and 2.55 cords per lineal foot; poles, 0.13 and 0.35 cord; stone for mattress, 0.63 cu. yd. per square; stone for paving, 3.03 cu. yds. per square; total stone, 5.74 cu. yds. per lineal foot; wire, 5.36 lbs. per square, and 20.98 lbs. per lineal foot; wire cable, 4.28 and 14.92 lbs. The work cost $27 08 per lineal foot.

LOUISIANA BEND, 1892 AND 1893.

The work comprised woven mats and upper-bank paving. The distribution of materials was as follows: Brush, 0.88 cord per square and 2.63 cords per lineal foot; poles, 0.17 and 0.44 cord; stone for mat, 0.63 cu. yd. per square; stone for paving, 3.58 cu. yds. per square; total stone, 6.25 cu. yds. per lineal foot; wire, 5.61 lbs. per square and 20.14 lbs. per lineal foot; wire cable, 3.53 and 10.69 lbs.

BOLIVAR FRONT, 1893.

This work was a mat 300 ft. wide, 2 ft. thick at the upper edge and 1 ft. at the lower. The distribution of the materials was as follows: Brush, 0.98 cord per square; poles, 0.15 cord; stone, 0.53 cu. yd.; wire, 5.5 lbs.; wire cable, 4.29 lbs.; spikes, 0.75 lb.

HOPEFIELD BEND, 1893 AND 1894.

The work included a fascine mattress 310 ft. wide and connecting fascine mattresses. The material in the 310-ft. mattress was distributed as follows: Brush, 1.639 cords per square; poles, 0.053 cord; stone, 0.625 ton; steel wire, 4.861 lbs.; copper wire, 0.546 lbs.; wire strand, 10.965 lbs.; clamps, 1.5. The cost per square constructed was $5 94 and the cost per square of bank covered was $6 07. The distribution of the material in the connecting mattresses was as follows: Brush, 2.355 cords per square; poles, 0.122 cord; stone, 0.66 ton. The cost was $6.987 per square.

DISTRIBUTION OF MATERIAL, 1894.

Material.	Ashbrook Neck.	Greenville.	Lake Providence.
Brush per square, woven mat, cords	1.163	1.157	0.98
Brush per square, fascine mat, cords	....	....	1.37
Poles per square, woven mat, cords	0.214	0.200	0.14
Stone per lineal foot, cubic yards	6.76	6.66	7.3
Wire per lineal foot, pounds	28.35	30.63	25.38
Wire strand per lineal foot, pounds	15.03	16.00	25.54
Spikes per lineal foot, pounds	4.47	3.20	1.89

APPENDIX B.—Cost of Bank Protection Work, Per Unit, from 1878 to 1895.

Date.	Locality.	Mattress work. Per square.	Connecting mat. Per square.	Upper-Bank Revetment, Including Grading. Brush work. Per square.	Upper-Bank Revetment, Including Grading. Stone paving. Per square.	Crib work. Per cubic foot.	Mat and upper-bank work combined. Per square.	Complete work. Per lineal foot.	Remarks.
1878	New Orleans Harbor	$12 87							Cane mats, 200′ x 24′.
1879	" " "	9 88						$13 38	" " "
1879	Delta Point, La.	12 00						18 00	Pin mats, 150′ x 50′.
1880	New Orleans Harbor	7 22							Cane mats, 200′ x 70′.
1882	Delta Point, La.	2 90		$6 89				14 00	Woven mats, 140′ x 400′.
1883	Plum Point Reach	6 30		6 40					Woven mats and brush revetment.
1882-1883	Lake Providence Reach						$4 47	11 20	Woven mats and brush revetment.
1884	New Orleans Harbor	7 60				$0 03½			Woven mats, 200′ x 350′, framed cribs.
1885-1886	Hopefield Bend	3 85		7 08					Woven mats, 150′ wide, brush revetment.
1886-1887	Memphis Harbor	3 17		5 17		.024			Woven mats, frame cribs, including grading.
1886-1887	" "	3 29							Woven mats, continuous revetment.
1887-1888	Hopefield Bend	2 89		4 38					Woven mats, continuous revetment.
1888	Greenville Harbor							20 20	Dike construction.
	New Orleans Harbor	7 54 and 9 11				.0457			Woven mats and cribs.
	Hopefield Bend						4 75		Woven mats, brush revetment.
	Bolivar Front						9 26	28 31	Woven mats, brush revetment.
1888-1889	Hopefield Bend	3 02		4 62					Woven mats, brush revetment.
1889	New Orleans Harbor	6 39							Woven mats.
1889	" " "	9 56				.04			Frame mats, frame cribs.

APPENDIX B.—COST OF BANK PROTECTION WORK, PER UNIT, FROM 1878 TO 1895—(*Continued*).

DATE.	Locality.	Mattress work. Per square.	Connecting mat. Per square.	Upper-Bank Revetment, Including Grading.		Crib work. Per cubic foot.	Mat and upper-bank work combined. Per square.	Complete work. Per lineal foot.	REMARKS.
				Brush work. Per square.	Stone paving. Per square.				
1889-1890	Hickman Harbor	3 46		6.00				24 77	Woven mats, brush revetment.
	Columbus Harbor					.04	6 70	22 65	Woven mats and cribs.
	Helena Harbor	4 89				.044			Woven mats and cribs.
	Greenville Harbor	4 56		7.71		.031 and .04			Woven mats and cribs.
	Bolivar Front						10 68		Woven mats and brush revetment.
1890-1891	New Orleans Harbor	10 20				.0357			Pin mats, frame cribs.
	Ashbrook Neck						7 69	30 42	Woven mats and brush revetment.
	New Orleans Harbor	9 95 and 9 48				.0358 and .0431			Pin mats and framed cribs.
1891-1892	Hopefield Bend	7 02	$3 36		6 12			19 57	Paving 10" stone.
	Ashbrook Neck	4 69	5 33	9.197	8 623			30 83	Woven mat pavement, 10".
	Greenville Harbor	4 50		9.54	8 59			29 52	" " " "
	Louisiana Bend						6 06	26 49	" " " "
	New Orleans Harbor	9 28				.037			Pin mats, frame cribs.
1892-1893	Ashport Bend	4 27	8 17 and 5 90		10 11			19 22	Woven mats and paving.
	Daniels Point	5 09	7 81						" " "
	Hopefield Bend	3 65	5 89		11 70				" " "
	Ashbrook Neck							29 07	" " "
	Greenville Harbor							27 08	" " "
	Louisiana Bend							27 86	" " "
	New Orleans Harbor	8 92							Pin mats.
1893-1894	New Madrid Harbor							27 78	Fascine mats and paving.
	Ashport Bend	6 28	11 85		10 11				" " "
	Hopefield Bend	6 03	6 99		9 20			31 52	" " "
	Bolivar Front						8 36	25 08	Woven mats and paving.
	Delta Point							26 32	" " "
1894-1895	Ashbrook Neck							30 25	" " "
	Greenville Harbor							28 22	" " "
	Lake Providence							30 41	Woven and fascine mats and paving.

In the finished work the percentage of cost of labor and material is about 45 and 55%, respectively.

CORRESPONDENCE.

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—The paper deals with the work on the lower Mississippi, but it may be of interest to mention briefly here the work on the upper Mississippi, in Wisconsin and Iowa, carried out in 1894–95 under Alexander Mackenzie, M. Am. Soc. C. E. The bank to be protected was cleared from trees, stumps and snags, and trimmed to a regular slope of one to two. The fascines were 20 ft. long and 12 to 15 ins. diameter, made of well-trimmed live brush closely packed together and tied with bands of wire or tarred rope not more than 3 ft. apart. These were made into mattresses 12 ft. long, a single layer being secured to three pairs of binding poles by ties of wire or tarred rope not more than 2 ft. apart. The mattresses were sunk at the foot of the bank, extending out into the river, and were loaded with a layer of rock 9 to 24 ins. thick, in pieces of 6 to 10 cu. ins., a sufficient amount of small stone or gravel being used to fill all interstices and form a compact mass. The larger stones were also laid to cover the bank above the edge of the mattress. Mr. Tratman.

The construction of brush dikes on the James River, in Virginia, specifications for which were issued in 1889 by William P. Craighill, Past-President Am. Soc. C. E., may also be referred to. These were built in water from 0 to 16 ft. deep at low tide, with a mean rise and fall of tide of 3½ ft. The main dike was approximately parallel with the shore, with lateral dikes connecting it with the shore. The methods of construction were as follows:

First.—Two rows of poles were driven 6 ft. apart, the poles being of pine, 8 ins. diameter at the small end and 35 ft. long (or in some cases 25 ft.), spaced 8 ft. center to center, and sawed off to 7 ft. above high water. Between these and at right angles to the current was placed a layer of live brush to a width of 30 ft. The bottom layer, 3 ft. thick, was of small trees or saplings of sufficient length to be tied together in sections, and projecting 15 ft. from the outside row of poles. This was loaded down with not less than 2 tons of stone or gravel per linear foot of dike. Upon this, and crosswise of the bottom layer, brush was filled in and well packed between the two rows of piles up to the level of the tops of the piles, after which the piles were tied together longitudinally and transversely with galvanized wire of No. 12 American gauge, each set having at least 12 strands of wire, six on each side.

Second.—Similar to the first, but without the bottom layer of brush and stone.

Third.—Where the bottom was so rocky that piles could not be driven, three rows of logs were laid parallel with the current, the rows being 10 ft. apart, made of logs 25 ft. long and 8 ins. diameter at the smaller end. Where the ends of the logs lapped they were bound by

Mr. Tratman. three strands of No. 12 galvanized iron wire. Upon these were laid 8-in. cross logs 3 ft. apart, each fastened to the lower poles by two strands of No. 12 galvanized wire. Upon these, and parallel with the lower logs, brush was piled to a depth of 3 ft., when another layer of cross logs was added, and secured to the cross logs below at every intersection with the bottom logs and half way between the intersections. The 3-ft. layers of brush, separated by rows of cross logs, were carried up until the low-water surface was reached. The dike was then sunk by loading it with stone or gravel, after which it was further consolidated by putting on 2 tons of hard stone per linear foot of dike.

In the regulation of the River Isar, a mountain stream of Bavaria, a system of suspended mattresses has been employed. The heels of the fascines are attached to a row of piling, so as to form a slightly pendulous inclined wall, which checks the current and causes the detritus to be deposited in the comparatively still water behind the fascines, the artificial bank being afterward protected by mattress revetment.

Mattress revetment has been employed for shore protection on Lake Erie, and the following is a description of this work from specifications by Capt. F. A. Mahan for shore protection at Erie, Pa., in 1888. The protection consists of a row of oak piles parallel with and 100 ft. from the shore, 6 ft. center to center, driven 15 ft. into the bed of the lake, and cut off 3 ft. above water. On each side and 12 ins. above the water line is a 6 x 12-in. waling piece, and on the outer side are sheeting piles placed close together, driven 7 ft. into the ground, secured to the waling piece and having another waling piece fastened on the outside. In the rear of this is a brush mattress 20 ft. wide, weighted down by stone. The mattresses are made as follows: Fascines 20 ft. long were made by binding together saplings not less than 13 ft. long or more than 2 ins. diameter at the butt, laid alternately, butts and tips, to form compact bundles 12 ins. diameter, each bundle having six fastenings of No. 10 B. W. G. wire, the extreme ones 6 ins. from the ends. For each mattress there are four poles 29 ft. long and 6 ins. diameter at the smaller end, placed 6 ft. center to center. Across these were laid the fascines, bound by No. 10 wire, passing alternately over two and under one fascine in succession, the wire also passing around the poles. The completed mattresses were towed into place and sunk by loading them with stone, close-grained limestone or granite, in blocks of 100 to 200 lbs. weight.

It would be interesting to know if mattress revetment has been employed for shore protection on lake or sea coast in positions where it is subjected to wave attacks. The writer is under the impression that some such system was employed a few years ago at Brighton Beach, on Coney Island, N. Y., where, however, the Atlantic waves undermined it and broke it to pieces.

Mr. Starling.

WILLIAM STARLING, M. Am. Soc. C. E.—The paper deals with a very important feature of river improvement, which has received an extraordinary development under the Mississippi River Commission. It is not by any means a novel contrivance, for it has been in use in Europe for a century or more. In its application to the peculiar conditions of the Mississippi, it has been necessary to depart more or less widely from the methods in use elsewhere. Many of the devices employed have been original, and evolved from the necessities of the case. The great size and violence of the big American stream and the extraordinary instability of its banks and bed demand works of special strength and dimensions. Brush has to be obtained from the wild growths which spring up spontaneously on the bars and foreshores. It is larger and rougher than the brush of the European markets, which is mostly an artificial product, raised for the special purpose for which it is employed. It is interesting to observe that the latest constructions of bank revetments differ less from the foreign types than those of an earlier date.

It is with the details of the work as it is practiced on the Mississippi that the paper deals; and the author has preferred to confine himself to such details rather than to go into the general principles of bank revetment as a branch of river improvement. The author is an authority on the subject of which he writes, as he has been connected with river improvement since its beginnings on the Mississippi. It is well known to those who have kept up with the progress of the latter work that bank protection was not adopted as a principle without violent opposition. The late James B. Eads threw the whole weight of his great name and abilities against it. The friends of revetment believed and still believe that by preventing the caving of banks, they would cut off the supply of material for building up the shoals below, and that thus some of the principal obstacles to navigation would be removed. Mr. Eads did not concur in this view. He thought that if the water was already fully loaded with sediment, it would stop caving, even in concave bends. His remedy for the evil was therefore to contract the wide places above the caving reaches. He was opposed to direct bank protection, first, on account of the enormous expense involved; second, because he thought the work ineffective as a means of improving navigation, and third, because he did not believe that the revetments could be maintained. The matter will be found fully discussed in Mr. Eads' numerous letters, in the paper on caving banks* by B. M. Harrod, M. Am. Soc. C. E., and in other places.

The old inhabitants and the steamboatmen were not only incredulous as to the success of bank protection, but they were sure it could not be accomplished. All the money in the United States Treasury could not do it. The first puny efforts that were made seemed almost

* Published in pamphlet form in 1886.

Mr. Starling. to justify their gloomy forebodings, and it was only by taking to heart the lessons taught by repeated failures that success has at last been attained.

The experience of the last 15 or 16 years has resulted, as the author has noted, in a continuous advance in the direction of strength and expensiveness, until the cost of a thorough system of bank protection in a badly caving reach is about $30 per linear foot. The work thus constructed is not absolutely permanent. Sooner or later, as stated in the paper, there occurs a scour at the foot of the revetment, which causes the latter to assume a steeper slope, and frequently results in a sliding down of parts of the structure, attended with breaks in the fabric, and sometimes with partial erosion in the bank thus left exposed. These damages are not usually extensive, nor is the repair of them generally very costly.

The latest conclusion to which the Mississippi River Commission has come seems to be that bank revetment is a valuable and effective means of preserving the shores of the river from erosion, and in certain situations is the legitimate and necessary remedy to be applied; as, for instance, for the prevention of a cut-off, for the preservation of a

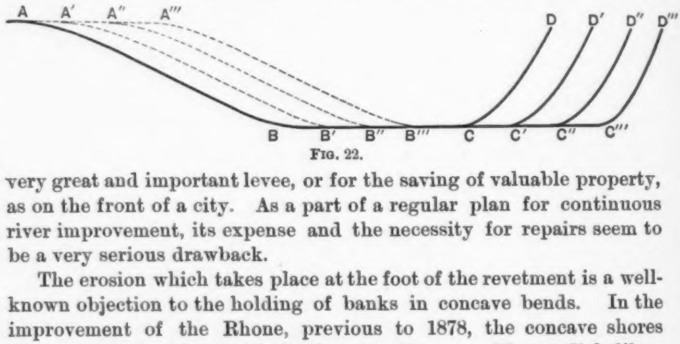

Fig. 22.

very great and important levee, or for the saving of valuable property, as on the front of a city. As a part of a regular plan for continuous river improvement, its expense and the necessity for repairs seem to be a very serious drawback.

The erosion which takes place at the foot of the revetment is a well-known objection to the holding of banks in concave bends. In the improvement of the Rhone, previous to 1878, the concave shores were provided either with bank protection or with parallel dikes. The strong high-water current scoured the bed so deeply and produced so great a pool that during low-water stages the velocity of the current became insignificant, and the fall was concentrated at the shoals existing at the reversion points, a condition highly unfavorable to low-water navigation. The reason of this excessive scour seems not to have been satisfactorily explained. Surely the portion of the water in contact with the bottom will not scour any the more because the portion in contact with the revetment is prevented from scouring. The *rationale* of the process appears to be this: Before revetment and while bank erosion was progressing, the bottom scoured out at the same rate that it did after revetment, but the bank, being undermined,

fell in and made good the loss of material on the bottom. The net result of this process was a lateral erosion, whereby the bed of the river was shifted from right to left or the reverse. The point of attack of the current against the bottom was thus continually changed. The river which lately occupied the position *A B C D*, Fig. 22, has taken in succession the positions *A' B' C' D'*, *A'' B'' C'' D''*, etc. Now, if the bank *C D* be held by revetment so that it cannot fall in, the current makes its attack always at *C*, and the space scoured out is not filled up, but is augmented by each successive invasion of the current. Mr. Starling.

The author has alluded to the importance of selecting a point for beginning the work. In the earlier applications of bank protection, care was taken to rest the upper end of the work under a bar, or at a point where the bank was stationary, so that the revetment should not be flanked or taken in reverse by erosion above its commencement. It was found that the precaution was sometimes carried to excess. By the time 6 000 lin. ft. of work had been completed, perhaps half of it was rendered unnecessary by the advance down stream of the bar at its head. At Greenville, in 1891, when the town was threatened with destruction by a rapidly caving bank, it was decided to depart from the ordinary method and begin at the lower end of the caving reach, where the destruction was greatest and the necessity for action immediate. This course was accordingly adopted, and 6 000 lin. ft. of mattress was laid from below upward. It was feared that there would be a very serious loss of material at the upper end, but the apprehensions were not justified by the event, the damage being small. The bank caved away for a short distance above the head of the revetment and carried away 50 or 100 ft. of the latter. The pocket thus formed produced dead water, and the caving then ceased. Next year 4 500 ft. more were laid in the same way and with the same result. The success of these experiments induced the Mississippi River Commission to proceed in the same manner at Lake Providence in 1895, and doubtless this will be a well-recognized feature of practice in the future.

D. M. Currie, M. Am. Soc. C. E.—The author mentions having tried for years the form of protection used near St. Louis, termed the woven mattress, but finally notes its failure on the lower river, with the rest, without mentioning its success near St. Louis. This omission might be misleading to members not familiar with the facts. The woven mattress has been the standard form of construction for the protection of the subaqueous slopes of banks between St. Louis and the mouth of the Ohio River continuously since its adoption in 1881. The length of bank protected by this form within this period aggregates about 23 miles, and no protection has been lost or damaged on account of the failure of the mattress, showing that the form is efficient under the existing conditions, and emphasizing the difficulties met in the protection of the banks below Cairo. Mr. Currie.

Mr. Price. W. G. PRICE, M. Am. Soc. C. E.—The first submerged spur dikes used on the Mississippi River were constructed in the Gouldsboro' Bend of New Orleans Harbor, in 1884, and were designed by Col. Amos Stickney. These dikes have now been in place eleven years, and have withstood successfully a very swift current, which sets in very strong against this bank, where rapid caving was taking place before they were constructed.

At other places where this system has been used, and where it has not been so successful, the original plan has not been followed, and a cheaper and weaker one has been substituted. It is possible that the partial failure is due to this change of plan.

The dikes at Gouldsboro' were so constructed that all permanent fastenings were of wood, so that all the metal fastenings which were used in sinking the mattress and cribs might be removed, and the structure would still be strongly bound together. These dikes also had a mattress apron, which extended 119 ft. down stream from the top crib, to prevent the eddy which forms below the crib from cutting away the bank. The dikes built in the Third District and at Carrollton, in New Orleans Harbor, had the length of the mattress apron very much reduced in width. The two dikes built at Plaquemine in 1889 had a mattress apron 70 ft. wide, and after these dikes had been in place nearly two years, a careful examination of them was made by the writer, who found that the bank was being washed out below and close to the down-stream edge of the mattress, which was a sure indication that the apron was not wide enough to protect the bank from the eddy caused by the crib. The next three dikes, which were built at Plaquemine in 1891, had the apron reduced to a width of 65 ft., and the mattress and crib did not extend far enough out into the river to have a footing on the level bottom from which to brace up the bank. This change in the plan of the dikes was made, not with the expectation of making them better, but to reduce their cost. It is the opinion of the writer that this change of plan was the cause of the serious caving at Plaquemine which followed the construction of these three dikes, and was the cause of the failure of the dikes at Carrollton and in the Third District of New Orleans Harbor to protect properly the bank between them. The widths of apron required for various heights of crib and for different radii of curvature of river bank have not been precisely determined, but evidently it is not safe at any location to make the apron much narrower than those at Gouldsboro'.

The writer believes that the practice of using fastenings of metal in dikes and mattresses should be discontinued. It is necessary to use some metal fastenings to hold the cribs and mattress in place while sinking them, but they should not be essentially permanent parts of the structure.

Some years ago the writer had a chance to note the effect on plain

and galvanized wire of corrosion and the impact of particles of sand in suspension in a swift current in the upper Mississippi River. Where the current was not swift enough to carry sand against it, the plain steel annealed wire, No. 12, was corroded in about seven months so as to reduce the section one-half. In a swifter current, which carried sand in suspension, a No. 10 galvanized iron wire was reduced in section one-half in about three months, and the zinc was cut off in about 10 days. The wire was lifted out of the water so it could be seen once every day, and while the current was strong enough to carry sand in suspension no rust was found on it; which indicated that the entire reduction of section was caused by the impact of particles of sand. **Mr. Price.**

The mattress used in the dikes at Carrollton was bound with frames of sawed pine timber. Cottonwood timber would be just as good for this purpose if it were used while green, and it would be much cheaper. The frames extended in a direction normal to the bank line, so that they held the rock from being rolled down stream by the current. Willow poles, to hold the rock from rolling down the steep bank, were wired to the frames. After the wire has been destroyed by corrosion, the poles will give way. A better form of construction would be to use sawed timber in place of the poles, which could be fastened with wood pins to the upright pieces which project above the frames. This form of mattress is flexible, and will bend with its weight of rock so as to fit the uneven bed of the river; and if a part is broken down by excessive bending, it will not go to pieces. Great flexibility in a mattress is not necessary. The immense amount of wood, leaves, grass, roots, etc., which moves along the bottom of the Mississippi River will rapidly clog up any opening there may be under the up-stream edge of a thick mattress, and all other cavities down stream will then be quickly filled with sand.

The submerged spur dikes at Greenville were constructed of willows and poles, and bound together with wire and spikes, and they are liable to go to pieces after the metal fastenings have been destroyed.

The woven mattress is weak only along its edges, where the willows are bound with wire. The first break probably occurs at the deep-water edge, where the wire fastening is destroyed, and the swift currents bend the loosened willows down stream so as to release the first weaving pole, which is soon carried away, and then the next weaving pole is released, and the action continues until the mattress is gradually destroyed. That faults have occurred in the deep-water edge of the woven mattress probably does not indicate a lack of flexibility, but does indicate that the wire fastenings have been destroyed. After willow wood has been submerged for a few months it becomes heavier than water, so that when a mattress is being carried away no material comes to the surface. The mattress used in building the submerged

Mr. Price. spur dikes at Gouldsboro' was woven, but the edges were strengthened with a continuous crib filled with rock.

The fascine mattress as now used in the Mississippi is bound together with galvanized iron and silicon bronze wire. In swift currents it is possible that the sand will cut all this wire, so as to release the binding poles, and thus cause its destruction.

The mattress and cribs used in building the two dams across the Atchafalaya River, at Simsport, La., were all bound together with pins of wood, and for six years they have withstood a current over them which powerful steamships cannot stem at high water, except by passing up close to the shore. If the material in these dams had been bound with wire of any kind, they probably would have been destroyed within one or two years after they were completed.

Mr. Noble. ALFRED NOBLE, M. Am. Soc. C. E.—The paper is an extremely interesting history of the methods used for the protection of the banks of the Mississippi River below Cairo. In their development there has been little change in the general features, but the work has been steadily increased in strength and cost, the frail constructions first adopted having proved unequal to the task imposed. In the nature of things a large amount of experimental work had to be done; the engineers had almost no precedents to guide them in dealing with the prodigious problem of the regulation of the Mississippi, and it is not surprising or discreditable that so much of the work failed. If there had been no failures the conclusion would have been irresistible that much money had been wasted by constructions unnecessarily strong and expensive.

The tables of cost are of much value, but this value would be greatly increased if a proper allowance for plant were included so that the figures would represent the actual outlay. On this class of work a large floating equipment is required; in the moist climate of the lower Mississippi decay of this equipment goes on rapidly every month of the year, and the life of a barge is short. It will require extensive repairs in four or five years amounting almost to rebuilding, and a large annual expenditure afterward until abandoned. A proper allowance for the cost and maintenance of plant would probably increase the unit prices given in the paper at least 20 per cent.

It is to be regretted that the paper does not give a more complete statement of the results of bank protection at a few of the points where the most persistent work has been done. For instance, at Hopefield Bend just above the city of Memphis, work has been in progress nearly every year since 1883. All of the work done previous to 1890, it appears from the paper, was replaced before 1894, except in the upper end of the reach, where a sand bar had formed in front of the work and protection was no longer needed. A statement of the total cost at this locality, the amount of bank recession after the first protection

work was placed, and the cost of the work destroyed by successive floods, would give a vivid idea of the difficulty of the problem and some notion of the immense expenditure that will be required for the complete regulation of the stream, and might suggest doubt as whether the end to be gained would justify the outlay. However this may be as to the general question, there is no doubt as to the necessity of bank protection at certain points where large local and important public interests are so involved that the execution of improvements by local authorities is impracticable. An instance is afforded by Vicksburg, where a shipping and distributing point of considerable importance was nearly shut off from the river by a cut-off and the further travel of the channel was checked by the protection works at Delta Point. A still better illustration is given at Memphis, a place of much greater importance. Mr. Noble.

The city of Memphis is built on a bluff of a height of about 100 ft. above low water in the river. It is the only point for a long distance where the river flows against the bluff. At the upper end of the city is the mouth of Wolf River on which are located several saw mills, supplied with logs in rafts from the Mississippi; near the mouth is the transfer landing of the Little Rock and Memphis Railroad; below this the bank of the Mississippi is lined with warehouses for a distance of about half a mile, followed by a paved levee for the landing of steamboats, extending for a distance of another half mile, the two sections covering the business portion of the city. The Memphis Bridge is 1⅜ miles below the levee; about midway in this section are the terminal grounds of the Kansas City, Fort Scott and Memphis Railroad and its allied lines, situated on the bluff and having a river front of about half a mile. Immediately above the city is the stretch of river known as Hopefield Bend; in this stretch the course of the river is nearly normal to the general course of the valley and to the direction of the city front, and hence the current strikes squarely against it. Prior to 1878 the current struck the city front at its upper end, making it necessary to build the protection works described in the paper; at that time, however, the river was eroding the right bank in Hopefield Bend, or, in other words, this stretch of river was moving laterally down the valley. If not checked the result would be the destruction of Hopefield Point and the city would be shut off from the river. The revetment of the caving bank was undertaken to prevent this and to preserve the harbor.

In order to relieve the force of the current against the upper end of the city front it was deemed advisable to commence the revetment at the upper end of the stretch and carry it down stream from year to year. This would permit the cutting away of the bank in advance of the revetment; and the current would strike the Memphis front farther down stream and at a rather better angle. It was intended to build the revetment at the proper rate to stop the cutting and hold the bank

Mr. Noble. when the pressure against the upper end of the city front was somewhat relieved, but before any injurious filling could result in front of the transfer landing, the warehouses or the levee.

The proper execution of this plan required control of funds for completing the work at the exact time when the erosion of the bank in Hopefield Bend had reached the proper limit. At the critical period no funds were available, the cutting progressed rapidly with a corresponding fill on the opposite bank, and a sand bar, bare at a medium stage, formed in front of the city from the mouth of Wolf River to the paved levee and over-lapped its up-stream end. The force of the current was thrown against the bluff below the protected front, causing the loss of valuable ground, and in consequence a fund was raised by citizens of Memphis and expended under the supervision of the officers of the Mississippi River Commission for extending the protection down stream. The property of the railroad company referred to was below the new work and a considerable area fell into the river.

At the site where the Memphis Bridge was afterward built, there was formerly a strip of low ground several hundred feet in width under the foot of the bluff. With the conditions up stream changed, this began to wear away. During the winter of 1889-90 it had disappeared entirely as far down stream as the bridge line and a considerable quantity of earth had fallen from the bluff within 300 ft. of the bridge.

In order to stop this cutting in the immediate neighborhood of the bridge the chief engineer, George S. Morison, Past-President Am. Soc. C. E., decided to adopt, with some modifications, the method then in use by the Mississippi River Commission for the protection of cutting banks. The failures of river protection works which had already occurred pointed to the necessity of making the work stronger and loading it more heavily with rock, the latter remedying, to some extent, the want of flexibility in the mattresses and forcing them more closely to the bed of the stream. The mattresses were also made much heavier, the quantity of brush being nearly doubled and both longitudinal and transverse wire cables were used more freely.

The upper end of the protection work is 1 080 ft. above the bridge, the lower end 240 ft. below the bridge, making a total length of 1 320 ft.; the protected area is about 365 ft. wide, extending from high-water mark to deepest water in the channel, or very nearly to it. The conditions are in some respects more favorable than in Hopefield Bend, the ground not being alluvial silt, but the under portion of a bluff generally of friable clay with much gravel, which diminishes the danger, both from under-cutting and from scouring through the mattress. There is, however, a stratum of sand a short distance above low water, which yields readily to the current wherever exposed and explains some peculiar features in the caving of the bluff.

The work was undertaken in the fall of 1890. The equipment was

Mr. Noble.

similar to that used on government work; the mooring boats and mattresses were anchored mainly with boxes filled with rock, shore anchors being used only for the shore edge. The anchor lines were 1¼-in. wire cables. It had been intended to weave the subaqueous mattress in one piece 250 ft. wide and 1 300 ft. long, but a succession of rises made it necessary to sink it in four sections, the accumulation of drift against the mooring barges straining the anchor lines so severely in each case that there was imminent danger of losing the portion woven. The several sections were made to overlap each other, and the loading along the lines of junction was made specially heavy. Although the mattresses were woven in the manner which has proved so unsatisfactory at Hopefield Bend, the work has been entirely successful, a result which is believed to be due, not only to the more favorable ground at the site, but to the more substantial construction of the mattresses.

In the interval of two years between the date of the survey of the bridge site and the commencement of the construction of the bridge, the west bank receded about 200 ft., and the west pier, originally located at the bank, now came in the river. It was desired, not merely to prevent farther cutting, but to restore the former shore line. The method adopted to secure this, which proved entirely successful, was to build along the line to be restored, a screen mattress hung up by one edge to a trestle, its up-stream end 1 080 ft. above the bridge, its down-stream end 75 ft. below it, making a total length of 1 155 ft. The up-stream end was curved toward the existing bank and the small opening closed by a dike of brush and stone. The top of the dike and of the screen was above ordinary high water. The screen mattress was loosely woven and was designed to permit the passage of water through it with a reduced velocity, inducing the deposit of the greater part of the material held in suspension.

In carrying out this plan a foundation mattress was first woven and sunk on the bed of the river, the whole length of the proposed screen. It was 150 ft. wide and extended outside of the screen line about 100 ft. This was heavily loaded with rock, particularly on the outer edge, so that if under-cut it would follow the cutting closely. The upper portion of this mattress was made 250 ft. wide and extended 350 ft. above the cross dike with its in-shore edge as close to the bank as it could be floated.

The next step was to build a light pile trestle along the proposed screen line, driving the piles through the foundation mattress which protected them effectually from scour. The screen mattress was then woven, one edge hung to the top of the trestle on the river face, the width of the mattress being 25 ft. to 40 ft. greater than the distance from the top of the trestle to the ground so that a broad flap rested on the bottom; this was also loaded with rock. In order to farther check the

Mr. Noble. current near the lower end of the protected area, a short spur dike was built from the shore nearly out to the screen about 100 ft. above the bridge line; the top was left at first considerably below high-water level, but was afterward raised as the filling progressed. The effect of this work was apparent immediately after the first rise, and in two years the area behind the screen was filled nearly to its original level.

The screen mattress and trestle are temporary, of course, and the portion of the former above low water is no longer capable of resisting a vigorous attack of the river. During the last two years, however, the river has shown no tendency to encroach in that direction and while this condition continues no additional protection will be required, but if the bank should be attacked, the action is not likely to be violent, and it can be protected by the usual revetment.

An application of mattress protection, believed to be novel, was made in connection with the foundations of the two river piers, which were of masonry on pneumatic caissons. At the site of one of these piers the bed of the river was about 30 ft. below extreme low water; at the other, 10 ft. higher. The bed, which is of sand, to a depth of 50 ft., would scour if a caisson were lowered near it; the scour would be greatest at the up-stream end and would make it doubtful if the caisson could be landed safely on the river bottom. To guard against this contingency the chief engineer decided to protect the river-bed by a mattress at each pier site before bringing the caisson into position; the caisson to be landed upon it and sunk through it. The mattresses for this purpose were placed at both pier sites in 1889.

The pier site in deepest water was first taken in hand. The area to be covered was 400 ft. square. The weaving plant provided for a width of 240 ft. only, so that it was necessary to weave two mattresses to make up the required width.

The distance from shore, nearly 800 ft., as well as the fact that the main steamboat channel was in this opening, precluded the idea of anchoring the mattress and plant, either wholly or in part, from the shore: Boxes filled with stone were therefore placed in the river as anchors, to each of which two manilla lines 2 ins. in diameter were attached, one leading to the mooring barge, the other under the barge to the head of the mattress. The mattresses were woven in the manner fully described by the author. For the first mattress the ten anchors were 5-ft. cubes without projections. It was believed that they would sink into the bed of the river quickly and would be practically immovable. This did not prove to be the case. In the later course of the work box anchors were repeatedly moved from place to place, and there was no apparent difficulty in lifting them other than that due to their weight.

When the weaving of the first mattress was completed it was loaded evenly with rock until it barely floated; the up-stream end was con-

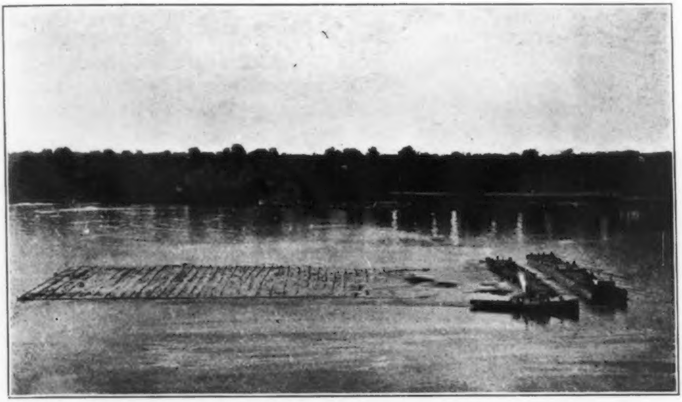

FIG. 1.

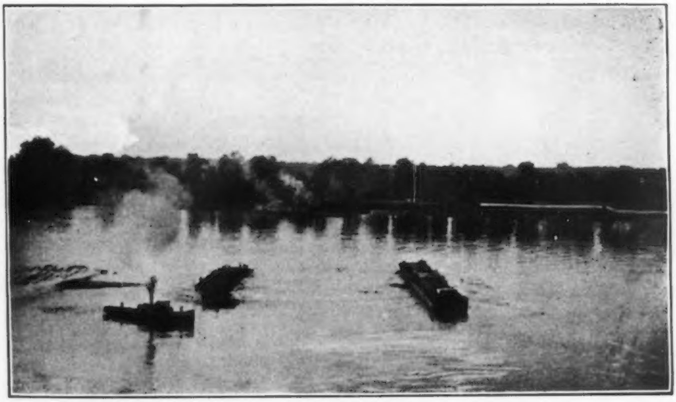

FIG. 2.

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nected to the anchors, as already stated, by lines passing under the mooring barges. During construction it was held up to the surface of the water by lines leading to timber heads along the down-stream side of the mooring barges; after the mattress was loaded these lines were slacked off enough to permit hauling across the head of the mattress two barges placed end to end and loaded with rock. When in position they were parallel to the mooring barges and immediately below them, and connected with them by lines; in moving across the head of the mattress enough rock was thrown from the barges to sink it as far as the lines would permit, and sufficiently to allow the floating of the barges over it. When finally in position, with a large force of men on board to throw off rock, the lines connecting the rock barges and mooring barges were slacked off steadily and uniformly, the men casting rock on the mattress as rapidly as possible while the current carried the rock barges over it. When about one-third of the mattress had been passed over, the lines joining the mattress-head to the mooring barges, then severely strained, were cast loose simultaneously, and the head began to sink to the bed of the river, swinging on the anchor lines, the down-stream end of the mattress still floating, being not fully loaded. As the head sank the mattress offered increasing obstruction to the current and before it reached the river bed in 40 ft. of water, the anchors began to drag and mattress and fleet moved down the river. When the head of the mattress reached the river-bed it increased the effective anchorage and the movement stopped; the current quickly forced the down-stream end under water, even before the rock barges had reached it. The whole operation of sinking had occupied less than six minutes. The movement is shown very well in Plate VI, Figs. 1 and 2, which are taken from the same point, the former before the movement commenced, the latter when it had stopped. The entire movement was 130 ft., and the head of the mattress was only 80 ft. above the center of the pier site instead of upward of 200 ft. as intended. The question arose at once whether it would be necessary to sink an additional mattress over the portion of the area intended to be protected, but still left uncovered. Inasmuch as the pier site would be actually protected, and as the stage of the river was low, with prospects of a continuance of the low stage, and, furthermore, as the season was growing late, while much work of this kind remained to be done, the question was decided in the negative. The building of the second mattress was then commenced according to the original plan. The anchors were increased in size to 6-ft. cubes; frames were made for the top and bottom of any convenient timber, usually 6 x 8-in. oak, to which the plank lining was spiked, the ends of the timbers projecting 10 to 20 ins. to give a better hold on the ground, as shown in Plate VII, Fig. 1. When the next mattress was sunk the anchors pulled slightly, and one or two of the lines broke, showing that the resistance

Mr. Noble. of the anchors was very nearly equal to the strength of the lines. The mattress was placed at almost exactly the spot desired; the caisson for the pier was then placed in position and landed safely upon the mattress without special incident.

On account of the lateness of the season, it was decided to place a single mattress, 240 x 400 ft., at the site of the remaining pier. This was done without difficulty, but after anchoring the caisson at the site a sharp rise of the river occurred, reaching a 23-ft. stage, and the velocity of the current became nearly 5 miles per hour. While the floating caisson was being built up and filled with concrete, the water was driven under its up-stream end with great force, and a scour of 4 or 5 ft. occurred through the mattress, showing that for those conditions the protection was imperfect. The mattress answered its purpose, however, and after landing there was no difficulty in leveling the caisson and sinking it.

While this caisson was afloat the strength of the anchorages was severely tested. The anchor lines were steel wire cables 1¼ ins. in diameter, and were attached generally to boxes of 7 ft. cube, similar in construction to those described. In adjusting the strains on the anchor lines they were frequently pulled with a 2-in. diameter manilla line rove in triple blocks, with the fall carried to a winch head on an ordinary Mundy hoisting engine. In order to get the strain desired, it was customary to take a run with the engine, then tighten the line on the winch and stall the engine. None of these anchors yielded under this severe pull. The anchors were sunk in about 30 ft. of water, and the anchor lines were 800 to 1 000 ft. long.

The piers of this bridge are founded in a hard, compact clay, underlying about 50 ft. of sand, and would doubtless carry safely the load imposed if the sand were scoured away; but obviously if the scour could be prevented and the frictional resistance of the sand made available for resisting settlement, the factor of safety would be increased. Furthermore, while the danger of scouring under the foundations in this material is exceedingly small, still an appreciable degree of security would be added if scour were prevented; the mattresses just described would accomplish this so long as they were preserved intact, but some doubt was felt in regard to this, because they had been subjected to very severe usage. In the main channel the velocity of the current had reached 8 miles per hour, and soundings showed that the edge of the mattress, if still in place, had been sunk about 20 ft. by under-cutting. For this reason it was thought best to sink a new mattress at each pier, and to load it very heavily with large stone; these mattresses were built in the same manner and with the same plant as before, except that the two weaving boats, instead of being placed together, end to end, were separated by an interval of 20 ft., which was closed by a temporary staging. When the mattress was woven down-

PLATE VII.
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NOBLE ON BANK REVETMENT.

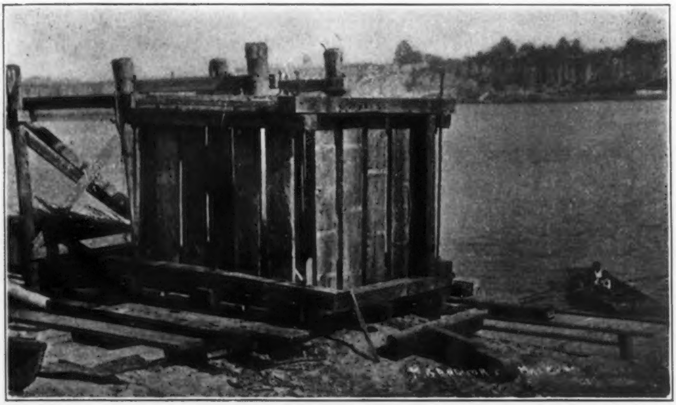

FIG. 1.

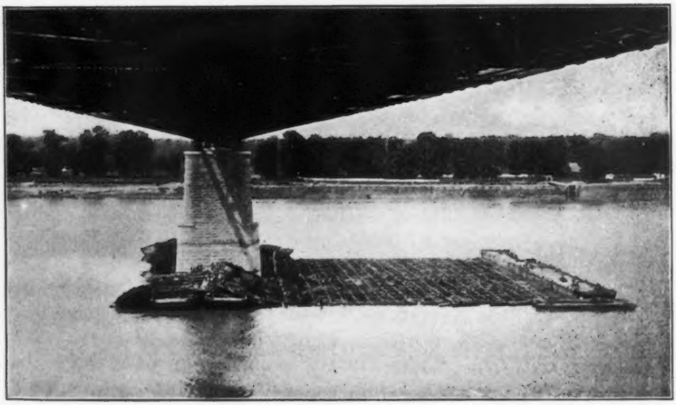

FIG. 2.

stream to the pier, the staging was removed until the pier had been passed. In this manner a continuous mattress was made at each pier 260 ft. wide by 400 ft. long, with a hole in the center just large enough to enclose the pier. The view shown in Plate VII, Fig. 2, was taken while the staging was removed and the weaving barges were passing the pier. After being sunk, the mattresses were covered with heavy quarry rock, running up to 2 or 3 tons in weight, to a depth of upwards of 5 ft. at the piers, and tapering off to 1 ft. at the edges of the mattresses. Soundings along the bridge line, which are still made regularly, indicate that this work is at yet uninjured. Mr. Noble.

The average cost of the mattress work at the Memphis Bridge per square of 100 sq. ft., not including the heavy riprap at the piers, was as follows :

1.1	Cords of brush and poles	$1 56
11.1	Lbs. wire and wire cables	46
1.1	Tons riprap	1 53
	Sundry materials	09
	Plant	1 90
	Labor	2 43
	Cost per square	$7 97

The large cost of plant is noticeable. A part of the floating equipment was not required for other work, and was wholly chargeable to this account, while a considerable portion was charged in part to other accounts. On the other hand, the plant was in use only two or three years; some of it was built, the remainder was bought at market rates, and at the end of the work all of it was sold at low prices as quickly as possible to avoid maintenance charges, the conditions being practically those of a forced sale. The cost of plant was, therefore, probably greater than on bank revetment work done by the United States Government. The figures cover every item of expenditure, except engineering expenses, which would not exceed 2 or 3 per cent.

H. St. L. Coppée, M. Am. Soc. C. E.—The difference in conditions existing in this country and Europe are quite marked. In the latter, as Mr. Starling states, the brush has to be cultivated with considerable trouble and care, while here in spite of the constant denudation for the purpose of revetment, the bars still contain sufficient quantities to supply the demand, a continual natural growth replacing that destroyed. Mr. Starling's explanation of the manner in which the bank caves where unprotected is undoubtedly correct, but his statement that the scour at the bottom of the slope beyond the mattress will not be augmented, is considered incorrect by the author for the following reasons : Mr. Coppée.

Mr. Coppée. When the bank is unprotected and irregular, the force and velocity of the current is decreased, not only by the loss of energy expended in reducing the bank, but also by its endeavor to carry in suspension a large amount of the abraided material. If the bank in the bend is protected with a smooth continuous revetment, there will be less obstruction to the general flow, and consequently greater velocity; and the transverse and downward currents near the shore will act with greater freedom and force. In other words the currents will be stronger, and as the scouring force increases with the square of the velocity, the abrasion will be greater at the foot of the slope where the bank is susceptible.

In regard to the point of beginning for extensive reaches of protection work, though in Greenville Harbor it was selected at the lower end where the caving was most rapid, and carried up stream, no rule has been made other than the general principle now adopted of commencing the work at the point where the caving is greatest and working up or down stream as would seem most advisable under the existing conditions, depending on the existence in the reach of other revetment, the value of property to be saved, etc.

A brush pile dike somewhat similar to that mentioned by Mr. Tratman as in use on the James River was constructed at Vicksburg in 1887, for the purpose of intercepting a current carrying silt into the harbor. The materials of construction were timber piles, brush, poles, wire spikes and rock. A mattress dike was built in the Plum Point Reach, near Gold Dust Landing, Tenn.,* not unlike those used on the James, where pile driving was impracticable.

Suspended screen mats and curtains have been used in this country on the Missouri and Mississippi Rivers. On the lower reaches of the latter river they were not generally successful in causing accretion.

The author did not intend to create the impression that woven mats were not considered of value at many points, because they were abandoned in the more exposed reaches for the fascine type of subaqueous revetment. On the contrary, there are many localities and many rivers in which their use is the best of practice.

Mr. Price is mistaken in supposing the cause of failure of spur dikes or submerged spurs, where such occurred in the upper districts, to have been due to defective design or weak construction. In every instance of which the author has record, the fault has been in the weak soil, strong currents, great oscillation of the water surface changing the point of attack, etc. A spur constructed under the direction of the author at Greenville, Miss., in 1889, at the head of a system about a mile in length, was flanked and undermined by the current, but not destroyed, remaining intact, the river cutting a new channel behind it. In the Third District and Carrollton bends, New Orleans

* See the "Report of the Chief of Engineers," U. S. Army, 1894, p. 2890.

Harbor, caving took place in the intervals between the dikes. This may have been due to insufficient width of apron and length of dike, but it caused the following expression of opinion by the officer in charge: Mr. Coppée.

"Spur dikes without intermediate revetment have been successful in some straight reaches and on concave banks of large radius, but in the abrupt bends the dikes alone are only locally effective."

In mattress construction Mr. Price lays great stress on the supposed weakness of the wire fastenings, and does not account for the effect of the large mass of stone covering the submerged structure. Where the mattresses are placed, as a rule, there is but a small amount of fine sand and no coarse sand in suspension in the water to cause abrasion. The deterioration from oxidation is probably not as great on the submerged as on the upper-bank work. The author has examined old revetment in which the wire was intact that had been subjected to a constant and strong current for over ten years.

Though it is the general opinion that the fascine mat is more flexible than the woven or frame mat, it is not so much to its flexibility, but rather to its imperviousness and its greater strength that is attributed its vast superiority over other forms. The framed pin and pole structure used under the spurs at New Orleans, and in the sill at Red River, would hardly stand the strains in sinking to which the fascine form is subjected.

Mr. Noble describes the use of large mattresses in a manner not generally familiar to river engineers; that is, as the foundation at first and afterward the protection of the caisson on which a bridge pier was constructed. In river work it is not often necessary to sink mattresses in the bed of the stream far distant from the bank, but when it is, the method adopted by Mr. Noble is generally followed, large wooden frame and rock anchors being used in place of shore fastenings.

The cost of plant, interest, deterioration, etc., was not given in the paper, because, though the value of the individual pieces of floating property could be readily ascertained, they are so differently distributed between different portions of the work in one season that it is practically impossible to tell what to charge to the different localities. The following list gives the pieces, with their approximate first cost, used by a bank protection party:

1 Steamboat, 200 tons, engine 17 x 6 ins., approximate dimensions, 130 x 25 x 5 ft.	$20 000
2 Mattress barges, 160 x 32 x 5 ft., each	4 500
2 Mooring barges, 160 x 30 x 5 ft., each	4 000
8 Brush barges, 120 x 30 x 6 ft., 250 cords capacity, each	3 000
8 Stone barges, 120 x 30 x 6 ft., 350 yards "	3 000
2 Line barges, 75 x 15 x 4 ft., each	1 000

Mr. Coppée. 2 Quarter boats and outfit, 120 x 23 x 5 ft., capacity 150 men, each.......... $4 000

1 Small office quarter boat..........	2 000
1 Hydraulic grader, including all hose and fixtures..........	20 000
6 Skiffs, each..........	20

The number of stone and brush barges necessary is governed by the distance to point of supply. The cost of lines and cables and the number required are too variable for estimation within reasonable limits.